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KNOWLEDGE FOR ACTION ON A SIMPLE AIMING TASK:
A DEVELOPMENTAL INVESTIGATION

BY

©

HILARY ANNE FINDLAY

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICAL EDUCATION
AND SPORT STUDIES

EDMONTON, ALBERTA
FALL, 1986

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled KNOWLEDGE FOR ACTION IN A SIMPLE AIMING TASK: A DEVELOPMENTAL STUDY submitted by HILARY ANNE FINDLAY in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Physical Education.

....

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Date: ..October,.....,.1986....

For my parents who lovingly put together such a rich environment that opportunities have always flowed and castles (even in Spain) have always been achievable!

ABSTRACT

A growing number of investigators have underscored the importance of the resources an individual brings to bear on not only the performance of a novel task, but its acquisition, and more generally, the concomitant effect on the total development of the individual. The objective of this investigation was to create a situation in which the interaction between the resources a person brings to a task and the expression of those resources could be observed.

A series of 4 experiments were performed using 72 female subjects aged 5, 7, 9, and 11 years. An indirect aiming task was used. Experiments 2 and 4 were designed to tap predominately declarative knowledge (knowing what) of the task and experiments 1 and 3 were designed to tap predominately procedural knowledge (knowing how) of the task. Assuming performance was reflective of subjects' understanding of the task, subjects were classified as low, medium or high knowledge in each experiment.

As expected, age trends were clearly apparent both qualitatively and quantitatively. With age, subjects reduced their error scores more rapidly and diplayed smaller absolute error scores. While a lack of younger subjects in the high knowledge category and older subjects in the low knowledge group made it difficult to

determine whether such changes were linked to knowledge differences or developmental differences, the strategies used by subjects seemed to be closely tied to the level of knowledge. For the low knowledge subjects (mainly younger children), strategies were based on repeated data-driven interactions with the environment. For the high knowledge subjects (mainly older children), strategies were based on pre-determined action sequences themselves based on a conceptual rule structure.

It was suggested that two levels of control could be identified. The first level, or orienting phase, depended heavily on the declarative knowledge of the subject. For those who had not yet acquired the necessary knowledge (both declarative and procedural), their action sequences were characterized by great variability. In the second level, or refinement phase, the focus was on perceptual factors associated with determining the degree of adjustment needed to decrease the error.

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CHAPTER 1

Introduction

On a daily basis we are confronted with novel situations or problems we must solve but for which we have not necessarily learned a specific solution. And yet we are able to cope with these situations, sometimes with immediate success, other times after several trials. Apparently then, we do have appropriate problem solving strategies at our disposal, or, at least we are able to draw on resources which may lead to appropriate solutions, even in the case of a novel task. More often than not, we are able to draw on past experiences of a similar nature for clues to a solution or are able to logically derive an appropriate solution from information inherent within the problem (Anderson, 1982). In other words, we are able to use old learning in new situations. Such behavior is indicative of both the parsimonious and the flexible nature of the human system and may be considered a major hallmark of intelligent behaviour (Campione, Brown, and Ferrara, 1982).

Intelligent behaviour is distinguished by an understanding of knowledge and the flexible use of that knowledge. Campione, Brown & Ferrara (1982) define understanding in terms of "appropriate use or ready access" (p.458). However, computers can be programmed to use various heuristics appropriately; animals can be conditioned to habitually exhibit specific responses to certain stimuli; humans too, can acquire solutions to specific problems by rote learning and apply those solutions under appropriate circumstances. Each of the above examples may exhibit understanding in terms of 'appropriate use' and 'ready access' and thus give the illusion of intelligence, but it is difficult to imbue each with intelligence. Markman (1981) perhaps most clearly identifies the notion of understanding associated with intelligence when she suggests that understanding leads to inferential processes. That is, it leads to and/or involves transforming, extending and relating information beyond the limits of a single instance. Pylyshyn (1978) used the term multiple access to denote the flexible use of information or knowledge under variable conditions. He also suggested that intelligent behavior includes the quality of reflexive access. By this he meant the ability to articulate as well as use the relationship or, "represent the representing relation itself" (Pylyshyn, 1978, p. 593). Similarly, Piaget (1976) makes a distinction between 'knowing' and 'knowing how' and suggests the latter as a necessary condition for cognizance or understanding. From a developmental perspective Piaget makes the observation that a child may correctly perform a certain act but be unable to explain how she did it, or perhaps explain incorrectly. Thus, there appears to exist a developmental gap between succeeding in action and being capable of explaining it (Piaget, 1976; De Sessa, 1981). Further, it is clear that children may observe an action but be unable to reproduce it.

Based on the assumption that motor skill acquisition is in fact a form of problem solving, the same criteria of intelligent behavior just discussed, should apply within the motor domain (Whiting, 1972). Within this domain, two fundamental observations have repeatedly been made with regard to the development of motor skills. First, the movement patterns, or action sequences, of a novice are characterized by great variability. As skill is gained the performance becomes increasingly more consistent and stable such that on repeated trials the basic pattern remains essentially unchanged. Secondly, associated with the development of consistency is a concurrent development in the flexibility with which the skill can be performed (Glencross, 1980). Using a tennis player as an example, the expert performer is able to adapt to variable conditions, e.g., court conditions or playing styles, and successfully execute a stroke on a consistent basis. The novice, even under constant conditions, will have difficulty keeping the ball within the court boundaries. Further, the skillful player is able to demonstrate greater versatility with her stroke, manipulating, for instance, the direction, velocity and spin of the ball at will. She is also able to recognize and use the same stroke for different strategic purposes. Intuitively, it would seem that the skilled player is able to adapt and bring under her control a far wider range of extraneous variables, to the novice such variables act as annoying and disruptive intrusions.

What is transferred in these situations that allows the skilled performer to choose and execute the same basic pattern under variable circumstances? Or, more simply, what is learned by the skilled player that the novice has not yet acquired? A growing number of investigators have emphasized the structure and development of the knowledge base as important components in the study of learning. They underscore the importance of the resources an individual brings to bear on not only the performance of a novel task, but its acquisition and, more generally, the concommitant effect on the total development of the individual. As noted by Flavell (1971), not only does our extant knowledge determine our current state, but it, "...shape[s] what and how we learn and remember" (p.273). Chi (1978) for example, in a classic study in which knowledge was manipulated independently of age, found adults with limited knowledge of chess were unable to memorize as many chess pieces as 10-year-old children who had an extensive knowledge of chess. Further, the adults required a greater number of trials to memorize the chess board positions than the children although the children could memorize fewer digits on a given trial and required a greater number of trials to learn 10 digits than the adults. Knowledge, in this case, was the primary determinant of performance, not age. A similar pattern of very robust effects has been found in such areas as soccer (Naus and Ornstein, 1983); basketball, volleyball and field hockey (Starkes and Deakin, 1984); physics (Chi, Feltovich, and Glaser, 1981); chess (Simon and Newell, 1972) among others.

As noted by Kail and Bisanz (1982), the way in which knowledge has been described varies among theorists. To a very large extent the organizational characteristics we choose to accept (at least metaphorically) are dependent upon the level of analysis we choose to use (Kugler, Kelso and Turvey, 1980; Farah and Kosslyn, 1982). Moreover, different concept representations and concept formation processes may be used by individuals at different developmental stages (Bruner, 1965; Piaget, 1970) and/or under different learning conditions (Farah and Koslyn, 1982). A common theme running throughout most hypothesized structures, however, is that knowledge is stored in terms of generic concepts at various levels of abstraction.

The question of the level of representation in the motor domain has been reviewed by Newell (1978), Barclay and Newell (1982) and Stelmach and Diggles (1983). They suggest that the main theories of motor learning have focused on the regulation of movement patterns as opposed to the concept of actions. Newell (1978) makes a distinction between movement and actions.

> Movements generally refer to the motion of the body and limb produced as a consequence of the spatial and temporal pattern of muscular contractions...actions are identified by the goal to which they are directed (e.g., open the door, lift the weight, etc.) or by specifying certain criteria to which the performer complies in what he does...as a consequence a variety of potential movements may be generated to complete any one act (Bernstein, 1967), and by the same token a variety of movements may be identified as a particular act (Mischel, 1969) (p.42).

It is *intention* which differentiates action from movement and is characterized by, "anticipation of the outcome, selection among appropriate means for achievement of the act and sustained direction of behavior during deployment of the means" (Bruner, 1973, p.2). This implies that a knowledge base, from which plans may evolve, is necessary for acts but is not necessary for movements and further, that a series of movements may be incorporated into a plan to make up an action.

As Stelmach and Diggles (1983) note, there has developed a polarization in the study of human motor behavior between the processes that, "contribute to the formulation of the intention to move or the plan of action" (p.85) and those involved in the specification and execution of those plans. In general, the current theoretical view points towards a system of control of movements represented as a heterarchy in which the intention to move determines the course of the movement. Increasingly more specific control parameters are determined by sub-ordinate structures of various levels of refinement (Turvey, 1977; Glencross, 1980; Bernstein, 1967; Schmidt, 1980; Keele, 1981). Some rapprochement between the two positions may be seen in the notion of a semantic knowledge base in which knowledge about objects becomes intimately linked to knowledge about actions (Namika, 1983) and the conscious control of action schemas (Wall and Bouffard, 1983; Norman and Shallice, 1982). As Barclay and Newell (1982) warn, "unless there is some conceptual action peg on which to hang response specifications the act will not be completed" (p.181).

The serve in tennis, the spike in volleyball, and the smash in badminton each derive their fundamental action from the basic principles of the overhand throwing pattern. With a few subtle permutations, the skilled performer is able to incorporate this basic pattern in a skillful execution of each sport specific action. Similarily, it is possible to identify many tactical redundancies which can be used in a variety of sports (e.g., the basic 'give and go' is common to most team sports). At a more fine grained level of analysis, it is also possible to identify the application of several very general laws of nature which are applicable to a variety of actions in a range of sport situations which will constrain the degrees of freedom associated with either the performance of a learned action or the acquisition of a novel skill. These natural laws may be described in very general cause and effect terms. The biomechanical literature is replete with examples of such laws or principles, (e.g., principles governing levers, the relations between mass, force and acceleration, the effect of gravity, etc.).

It has been suggested that a knowledge of both the underlying principles and the application of those principles (i.e., the cause and effect relations) will enhance both the maintenance and generalization of behaviors based upon them. Hendrickson and Schroeder (1941) are among the few published within the motor skill literature to suggest such a liason. Using a task which involved throwing a dart at a submerged target, they found that knowledge of the theory of refraction significantly facilitated performance. Further, the completeness of the theoretical information had a direct effect upon both initial learning and transfer.

Similarily, Siegler, Liebert and Liebert (1973) found knowledge of the rules governing Piaget's pendulum problem greatly facilitated performance on the task. Subjects were given either a set of rules governing the task, analogous problems to solve, a set of measurement tools to use in a trial or a combination of the rules and problems. Results indicated that subjects not given either the analogous problems or the conceptual rules had greater difficulty learning the task than those receiving the problems and/or the rules.

A knowledge of the cause and effect nature of certain principles in sport performance may also enhance both the ability to correct performance errors and the ability to anticipate imminent situations. A series of investigations by Allard (Allard, Graham, and Paarsalu, 1980; Allard, 1981) suggests that one factor distinguishing the expert performer (specifically the expert basketball player) from the novice is that the expert is able to vividly construct a mental representation of the basic tactical situations inherent within the game. She suggests the representation is made up of both a topological image of specific situations and the appropriate actions or responses in such situations. Previously, Allard and her collegues (Allard et al., 1980) found that basketball players recalled the positions of players and their movements in slides of typically occurring structured situations more accurately and in larger more complete chunks than did control subjects. It may be suggested that the expert players' representations included both declarative (or factual) knowledge of a situation and procedures for action within a particular situation. Within the representations of the novice players apparently this latter component was not present.

While much of the research related to the maintenance and generalization of strategic behavior has assumed complete comprehension of the structural components of the task (i.e., the cause and effect rule structure), such knowledge may not be intact and completely integrated in the less skilled. The partial or incomplete understandings of the novice and/or developmentally young will be reflected in their performance. That is, it may be suggested that inappropriate or less than skillful performance is indicative of the individual's current understanding of the task. The procedures one chooses to use in the execution of the task are derived from that understanding. Based on the outcome, i.e. the success or failure of such procedures, modifications may be made to the way in which the individual views the task and the procedures used in its execution.

It may be possible to structure a learning situation in which it is possible to view a person's current state of knowledge about a specific task. An opportunity in which procedures, that have been derived from this understanding and are used to perform the task could then be provided. By allowing the individual to see the resultant effect such procedures have in achieving this task, it may be possible to highlight the dynamic interaction between knowledge and performance in this situation.

Objectives

The objective of this study is to investigate the knowledge subjects have of the rules underlying a particular task. Subjects will be asked to make predictions on the task. These predictions will depend on the understanding the subjects have of the rules underlying the task and the development of appropriate procedures to apply that knowledge. Subjects will then be given the opportunity to apply this knowledge and view the effectiveness of their strategies, or procedures, in successfully completing the task. (It is assumed that because the rules underlying the prediction task are the same as those inherent within the application task, subjects will use the same strategies on both occassions.) The prediction task will then be repeated.

Changes in the task specific knowledge of subjects, coming as a result of the application of the procedures they felt would be effective in performing the previous task, will be inferred through changes in their prediction pattern. An age range of 5 to 11 years will be used such that age differences in the performance pattern may be observed. More specifically, the following questions will be asked:

1. Does children's knowledge of rules inherent within a problem task and essential to the solution of that task, vary with age?
2. Does the relationship between knowledge of the rules and the ability to use those rules in the solution to a specific problem vary with age?
3. Does the accuracy of children's predictions reflecting their declarative knowledge (i.e., the underlying rule structure) vary with age?
4. Is predictive knowledge necessary for successful completion of the task (i.e., hitting the target)?

Assumptions

Two basic assumptions underlie this investigation. First, human behavior may be characterized by some form of organization and further, this organization may be represented by a hierarchy of increasingly more powerful rules. Siegler (1983) defines rules as, "if-then statements that link conditions of applicability to conclusions to be reached or actions to be taken" (p.264). Further, the presence (and use) of such rules assumes a concomitant knowledge base from which the rules are derived. Secondly, during certain stages of skill acquisition, motor learning can be viewed as a form of problem solving and, as such, discussions of problem solving in the cognitive domain are pertinent to the motor domain.

Definitions

Declarative knowledge : a set of specific facts describing particular knowledge domains. It may be considered analogous to 'knowing what'.

Metacognitive knowledge : knowledge about one's own cognitive resources in a learning and/or performance situation.

Metacognitive process : self-regulatory or management function used by an individual during learning and certain performance situations.

Metacognitive skill : the functional manifestation of metacognitive knowledge and metacognitive processes.

Procedural knowledge : knowledge of a domain bound with procedures for its use. It may be considered analogous to 'knowing how'.

Rule : described by Siegler (1983) as, "if-then statements that link conditions of applicability to conclusions to be reached or actions to be taken" (p.264). Behavior can thus be said to be rule governed to the extent that constraints are consistently applied to possible actions taken towards a specific purpose or goal.

Limitations

The study is limited to the extent that:

1. the observed behavior is representative of the hypothesized covert knowledge structure. That is, the pattern of behavior observed reflects the underlying content of the specific knowledge structure associated with the task being studied;
2. individual cognitive styles differentially affect the problem solving behavior under investigation;
3. subjects respond optimally (this will be influenced by their level of motivation and attention to the task).

Delimitations

Subjects in the study were 5, 7, 9 and 11 year old children drawn from selected local schools. Only females were used and all subjects had to be within the normal IQ range.

CHAPTER 2

Literature Review

Knowledge

The review will be divided into four major sections. The first section will focus on the development of knowledge as a critical factor in performance. A major focus will be placed on the concept of metacognition. Substantial resources are available in this area relating to both conceptual and methodological considerations which are pertinent to a more general analysis of knowledge as a major determinant in performance. The effects of knowledge on performance in terms of processing efficiency and organization will then be considered in section two. The third major section will look at factors relating to the process of acquiring skill or competence. Various phenomenological studies will be used to highlight these factors. Finally, a theoretical framework for the acquisition of skill will be presented.

Structural Dimensions of Knowledge

Knowledge has typically been represented in the form of schemas. Generally, schemas may be described as networks or packages of inter-related knowledge. Two other metaphors commonly used to represent knowledge are networks (Anderson, 1976, Collins and Loftus, 1972) and production rules (Simon and Newell, 1972; Klahr and Wallace, 1976). Networks consist of a lattice of nodes and links - each node standing for a particular concept and the link for the particular association or relation between nodes. Learning in this type of model consists of the acquisition of new nodes and new links between existing nodes. Production rules on the other hand, consist of a propositional relationship, i.e., a condition paired with a consequent action (often represented as if-then pairings). A group of production rules directed to the same goal (and/or subgoals) is said to form a production system. Learning in this system occurs with the addition of new rules.

Recent views of knowledge systems stress that schemas organize units of knowledge and, as such, they are at a higher level conceptually than networks or production rules (Chi and Rees, 1983). That is, a set of nodes tightly inter-related by many links or, one or several production systems joined by a common goal, can be viewed as a schema.

Classification of Knowledge

While the hypothesized structural dimensions of knowledge vary among theorists (c.f. discussions by Kail and Bisanz, 1983; Chi and Rees, 1983; Winograd, 1979), most models of memory and problem solving incorporate the schematic accumulation of two basic types of knowledge: declarative or factual knowledge about the world and procedural knowledge, that is knowledge of how to do things. Wall, McClements, Bouffard and Findlay (1985) have suggested another category of knowledge, that of affective knowledge. Affective knowledge refers to the subjective feelings about one's self and one's actions. The authors suggest these feelings affect the motivational state of an individual and, as such, influence the acquisition of both declarative and procedural knowledge (p. 31).

Earlier investigations of the difference between mature and immature learners focused on the presence of task appropriate declarative knowledge and the proceduralization of such knowledge in the execution of a task. While the terms declarative and procedural knowledge were not explicitly used, the focus was on the presence of task specific strategies within an individual's repertoire and the extent to which such strategies were used under appropriate conditions (Flavell, 1970; Glaser, 1984; Singer, 1978). The term production deficiency was applied when an individual did not spontaneously produce the appropriate task strategies but, if instructed to do so, could use such strategies to improve performance. A mediational deficiency was said to exist when, even if instructed, an individual could not invoke the use of task-appropriate strategies or, the use of such strategies did not enhance performance (Flavell, 1970).

This distinction between strategic and non-strategic behavior has frequently been used to identify and categorize performance deficits relative to age, level of intelligence and experience. In terms of the first area, mediational and production deficiencies have typically been identified as stages in the development of a mature strategy (Reese, 1976). The general trend is that young children (5 to 7 years of age) typically display mediational deficits. Children 8 to 10 years of age may display some spontaneous activity, however, by and large they are characterized as displaying a production deficiency. By the age of 11 to 12 years, most children are mature strategy users, at least, in the areas of memory and problem solving studied (Kail and Hagen, 1982). In terms of the second area i.e., level of intelligence, an extensive line of research associated with Ann Brown and her colleagues (Brown, 1975, 1978; Campione and Brown, 1977) and Belmont and Butterfield (Belmont and Butterfield, 1969,1977) strongly supports a production deficiency in the mentally retarded. The general findings to emerge from this work indicate that subjects initially fail to produce appropriate strategies when left to their own devices; however, with extensive and very explicit instructions, they can use most of the strategies employed thus far in the research. Finally, in terms of experience, there is some evidence to suggest that novice performers may not use the appropriate strategies on a new task even though those strategies are within their capabilities. While children are generally universal novices (Brown and DeLoache, 1978), their naivete is not necessarily related only to age but is also a function of inexperience in a new problem situation (Chi, 1977, 1978).

Metacognition as a Form of Knowledge

Investigations into the variables underlying the spontaneous use of strategies have centered on the study of metacognitive skills (Brown, 1975; Flavell and Wellman, 1977) and led to its inclusion as another important type of knowledge. In the most general sense, metacognition refers to an understanding of one's cognitive system. However, the notion of metacognition has been embroiled in both a conceptual and methodological debate resulting in rather a murky picture. As noted by several investigators (e.g., Lawson, 1984; Wong, in press; Flavell, 1976) in the more specific case, the gist of the term metacognition has not been applied consistently by researchers, making it difficult to get a firm grasp on the concept and the role it plays in cognition. Lawson (1984) among others (e.g., Cavanaugh and Perlmutter 1982; Campione, Brown and Ferrar, 1982) in an attempt to clarify the concept, argue for the division of metacognition into two separate or distinct dimensions: a knowledge dimension, variously labelled metacognitive knowledge or metacognition, which refers to knowledge about one's own cognitive resources in the context of a learning situation and, a control dimension, variously labeled executive processes or executive control, which pertains to the self-regulatory or management functions used by an active learner in problem solving situations.

Alternatively, Wellman (1983) suggests the picture is not as neat as a simple dichotomy of terms. He describes metacognition as a 'fuzzy' concept not at all accessible to explicit definition. While certain instances such as those involving the two dimensions mentioned above, clearly engender the central distinction that has typically been associated with metacognition, (i.e., the difference between engaging in some form of cognitive activity and being aware of such involvement), other instances are not as easily classified (e.g., Flavell's (1977, 1978) metacognitive experiences). While they may share some common features, Wellman (1983) suggests they remain distinct in many other respects. "While the subclasses do relate to the original

distinction in various ways, in the end the extended domain probably constitutes an array of different processes linked by family resemblances" (Wellman, 1983, p.34).
Metacognition then, may be better represented as a general rubric under which an array of related (but distinct) processes and knowledges exist.

The results of a study by Kurdek and Burt (1981) may in fact reflect such an interpretation. The authors investigated the relationship between skills across three metacognitive domains: metacommmunicative skills, metamemory skills and metasocial-cognitive skills. No consistent pattern of relationships across six grade levels (grades 1-6) between the three domains was apparent. Moreover, correlations across the tasks were positive but low. Based on the assumption that metacognitive knowledge and skills are domain specific and quite distinct (Wellman, 1983; Lawson, 1984), such a pattern of results should not be unexpected.

Investigations concerned with the notion of metacognition provided the first insights into the role of knowledge related factors in determining performance outcomes (particularly in the area of memory performance). Since the early 1970's such investigations have broadened to include a more generic perspective of knowledge. Many of the problems, both methodological and conceptual, which have been associated with the study of metacognitive knowledge and metacognitive skill, would seem to be inherent in investigations of knowledge factors from a more general perspective. The next section will focus on two particular issues which have been pertinent to the study of metacognition and need to be considered in the more general interpretation of the effects of knowledge on performance. The first issue to be discussed has to do with the interactive nature of the factors influencing performance and the way in which such factors can be interpreted. The second issue relates to methodological problems in the study of metacognition.

The Interaction of Factors in Metacognitive Performance

The bulk of the research in the area of metacognitive performance has focused on metacognitive knowledge (Flavell and Wellman, 1977; Flavell, 1978, 1981). Flavell describes two main types of memory knowledge, sensitivity knowledge and variable knowledge. Sensitivity refers to one's awareness that different tasks require different types and degrees of strategic behavior. Variable knowledge, the second type of memory knowledge, is sub-divided into three components. Person variables refer to knowledge about one's self as a learner and about one's knowledge state with respect to a task. That is, one must not only know about one's capabilities and limitations as a learner but must also be cognizant of what one does not know about a particular task situation (Brown, 1978). Task variables refer to characteristics of the task, such as the nature of the task and the demands of the task, which will influence performance. Strategy variables refer to knowledge about strategies, their usefulness, appropriate application, etc.. According to Flavell (1978), each of these three variable types interacts with each other to influence performance. While the bulk of the research has used this (partial) taxonomy, Flavell (1981) has in fact proposed a more extensive interactive model somewhat similar to the tetrahedral model of Jenkins (1979) and adapted by Brown (1982). Use of such an interactive model has also been advocated by others (e.g., Wong in press; Wellman 1983).

Four factors play a dominant role in Brown's (1982) interpretation of the model: the repertoire of strategic activities that a learner can bring to the learning context; characteristics of the learner - skills, knowledge, attitudes, capacity, etc., the nature of the material to be acquired and finally, the nature of the criterial task or end product desired. There is ample evidence across a number of domains demonstrating the effect on performance of each of these factors studied independently. Further, Brown (1982) has reviewed some evidence from studies using two way interactions; however, very little research has been done using such an interactive model in the study of metacognition. Two lines of theorizing are informative in this regard, particularly in light of their developmental implications for an interactive model of metacognition and knowledge in general.

Lawson (1984) has provided a theoretical analysis of the pattern of behavior one can expect in executive processing and metacognitive knowledge with different levels of expertise. He cites two cases, one in which the expert is an adult and one in which the expert is a child. In the case of the two adults (one an expert and the other a novice in a particular domain area) the superiority of the expert is due, in large part, to a more extensive knowledge base in the specific area. While both adults can be assured of having equal competency in general executive processing, the advantage of the superior knowledge base will be reflected in a more effective application of executive activity and subsequently in superior metacognitive knowledge due to the enhanced opportunity to reflect on one's cognitive activities in the area.

In the case in which the expert is a child (and the adult a novice) the level of development of the child introduces a new factor to the expected levels of metacognitive knowledge and executive processing exhibited. Lawson (1984) suggests that the degree of expertise of an individual must be taken into account in making assessments of metacognitive knowledge and/or executive processing. Brown et al., (1978) have suggested executive processing is a relatively late developing phenomena - at least in the tasks they selected. On the other hand, investigators have found evidence of such activity in children as young as 8 years of age (Paris and Myers, 1981) and evidence of metamemorial knowledge in children as young as 6 years of age using an extremely simple task (Kreutzer, Leonard and Flavell, 1975). Thus, while developmental status may have an effect on the level of executive activity and metacognitive knowledge exhibited, it seems clear that the nature of the task as well as the level of expertise of the child must also be taken into consideration.

The adult novice (in the second case) had greater opportunity to experience a range of problem solving situations and thus can be expected to have developed an extensive repertoire of executive processes (a situation quite opposite to what one would expect if the child had been the novice). According to Lawson (1984), this greater competency in executive processing and wider experience as a problem solver may compensate somewhat for the limited knowledge base and subsequent limited task specific strategies.

In summary, Lawson has suggested that several factors must be taken into account when interpreting the behavioral evidence of metacognitive knowledge and/or executive processing (or lack of evidence of such phenomena), i.e., the level of development of the individual in a specific task domain, the nature of the criterion task and the level of expertise of the individual. Further, the interactive effects of these factors must be considered.

The second line of theorizing comes from Wellman (1983) who has also emphasized the importance of looking at the interaction of several variables when interpreting a child's metacognitive behavior. More specifically, Wellman (1983) asks the question, 'what lies behind the child's metacognitive judgements?' Using the example of judging one's cognitive limitations, traditionally single variable studies have suggested that children, with age, increasingly recognize the importance of considering the number of variables in determining their own ability to remember a group of items. Wellman et al., (1981) suggest this is only part of the picture. That is, children integrate information from a variety of sources in making a decision or memory judgement. In their study, children integrated information about both the number of items to be remembered and the effort needed to complete the task when making their judgements. They found that effort was a much more dominant variable at first but decreased with age at which point the number of items became increasingly the more important variable. Wellman (1983) concluded: "...what a child judges as an isolated metamemory task is only a manifestation of a complex inter-related system of knowledge about memory (p.38)".

Together, Wellman (1983) and Lawson (1984) both recognize the very complex interactive nature of the concept of metacognition and suggest that from an empirical perspective, research strategies must be sensitive to and congruent with such a view. While the previously sighted investigations only indirectly suggest the complex interaction of knowledge factors through reference to metacognition as a form of knowledge, it may be suggested a similar perspective should be taken in the study of knowledge factors in general. That is, researchers must be sensitive to the influence of external factors on the performance of an individual.

Methodological Problems in the Study of Metacognition

The second area to be discussed focuses on the methodological problems in research dealing with metacognition. Measures of metacognitive knowledge have generally been attained through introspective surveys and questionnaires or through measures of performance, e.g., prediction, recall readiness or feeling-of-knowing assessments. Historically, introspective measures have been criticized with respect to the accessibility of the cognitive processes to introspective analysis and the completeness and accuracy of introspective (usually verbal) reports (Humphrey, 1951). Cavanaugh and Perlmutter (1982) note two additional problems with much of the current metamemory research - a dirth of replication studies and a general lack of indices related to the reliability of the measures. Ericsson and Simon (1980) while recognizing the potential pitfalls of such methods, note that with proper controls, introspective techniques can provide useful and reliable information. They join others (Rushton, Brainerd and Pressley, 1983) in making a strong plea for more convergent measures in metamemory research.

Notwithstanding these comments, Borkowski and Cavanaugh (1982) note that metamemory (or more generally metacognition) has theoretical significance only in so far as it proves useful in explaining individual differences in strategic behaviour, that is, an individual's failure to use an available strategy may be due to a lack of appreciation for that strategy's utility (Flavell, 1978; Brown and DeLoache, 1978). While much of the research (some previously mentioned) has attempted to causally link metamemory to strategy use and thus performance, the results have produced minimal and often conflicting correlations. One problem was just alluded to, i.e., the reliability of the measures. In the same vein, research procedures often do not provide a valid test of the assumptions under scrutiny. Do the tasks selected actually require subjects to engage in metacognitive activity as defined by the researchers, i.e., what does the critical task tap? Does the metacognitive knowledge assessment bear a close resemblance to the performance task? Lawson (1984) suggests that some disparity in results can be accounted for by inappropriate research procedures.

A second problem, also mentioned earlier, relates to the pattern of results one should expect. For example, the basic research paradigm generally used attempts to correlate single variables (e.g., a single piece of metacognitive knowledge such as knowledge of organization, with a single behavior such as organizational behavior). However, results have been inconsistent; however, such empirical results are not surprising in light of some suggestions that the psychological reality is probably not so straight forward (Wellman, 1983; Brown, 1982; Flavell, 1981; Lawson, 1984). It seems much more likely that a number of knowledge variables interact to produce a particular behavior and that this pattern of interaction changes with development (Wellman et al., 1982). Further, patterns of relationships between metacognitive knowledge and performance can be expected to vary depending on the task characteristics. Not withstanding other intervening variables and interactions, as metacognitive knowledge in a specific area or about a specific task increases (e.g., the role and effect of organization in memory performance), the likelihood or strength of a specific (corresponding) behavior being produced will increase (Wellman, 1983). From another perspective, different tasks even ones resembling the original task, (including metacogntive tasks) may demand more or less knowledge to elicit a particular response (Bjorklund and Zeman, 1982). Thus, under one task condition an individual may display certain metacognitive skills but under another task condition or with another task, the same metacognitive skills may not be present.

A third problem area lies in the lack of independent measure of each component, i.e., metacognitive knowledge, strategy use and level of performance. Training study techniques have provided an alternative to traditional measures of metamemory and have overcome to some extent, this problem. Rather than simply looking at baseline performance, training studies use a general test-train-retest procedure. Measures of baseline performance are thus augmented by measures of the subject's responsiveness to training. Such techniques, while not prevalent in knowledge studies in general, provide a useful way to manipulate knowledge - related factors independent of age.

Training Studies: A Methodology for the Investigation of Knowledge Related Factors

Briefly, the training study procedure entails a detailed task analysis. Potential sources of individual differences are hypothesized. Subjects then receive training on one of the hypothesized factors. If performance improves, the task analysis is reinforced and the hypothesized difference receives support. To the extent that performance leaves something to be desired, the training process continues using a different factor (Campione, Brown and Ferrar, 1982; Campione and Brown, 1977; Borkowski and Cavanaugh, 1979). Efficacy of the instructed strategy is determined by the extent to which the strategy is maintained, i.e., the acquired strategy is continued on a task identical to that used in training, and the extent to which the strategy is transferred to other tasks. The tasks to which the strategy is transferred, while sharing some common features with the training task in terms of processing requirements, should typically require a modification of the trained strategy for it to be competely applicable to the new task (Campione and Brown, 1979).

Changes in the Training Study Format

Three main categories of training studies can be identified in the literature based on the amount of information given to the subjects: blind, informed and, self-control (Campione et al., 1982). Blind training studies, historically the earliest, aimed to induce strategic behavior but did not give subjects an explicit and concurrent understanding of the significance of the activity. While the training did enhance performance, it typically failed to lead to maintenance or generalization (Brown, Campione, Bray and Wilcox, 1973; Butterfield, Wambold and Belmont, 1973; Spitz, 1966, 1972; Campione and Brown, 1977, 1978). Following from the blind training studies were informed training studies which, once again, aimed to induce the use of strategic behavior but also gave subjects some information concerning the significance of the activity. Training of this sort led to some positive change in maintenance and generalization. For example, Borkowski, Levers and Gruenenfelder (1976) found that a brief film illustrating the use of a mediational strategy prior to training, enhanced strategy maintenance in normal children. Similarly, Ringel and Springer (1980) found that reinforcing the utility of a strategy (in this case a categorization strategy) improved performance and resulted in significant maintenance of the strategy. Kendall, Borkowski and Cavanaugh (1980) obtained similar improvement in the performance of mentally retarded children using an elaboration strategy. Belmont, Butterfield and Borkowski (1978) investigated the role of training in multiple (as opposed to single) contexts. Subjects were shown that a basic rehearsal strategy was useful on a variety of (similar) tasks, although it was necessary for the exact form of the strategy to be modified to take into account the unique demands of each task. Belmont et al., (1978) found some generalization in mentally retarded subjects trained in multiple contexts but no generalization in those trained in a single context. The results of these studies suggest that some individuals may not appreciate the utility of a specific strategy without explicit feedback. Providing that information resulted in both increased maintenance and generalization. The implication here is that some form of metacognitive activity was used. In cases where this activity is not spontaneously invoked (either due to a lack of metacognitive processing skill or due to a lack of metacognitive knowledge), this activity can be invoked in certain circumstances by providing some external information.

While some of these studies (e.g., Borkowski and Cavanaugh, 1979; Kendall, Borkowski and Cavanaugh, 1980) have provided independent measures of metacognitive knowledge (more specifically metamemory), cognitive strategies and performance, it is still not clear whether increased proficiency in executive skills purportedly enhanced through the training, actually led to performance benefits and, in turn, to an increase in metacognitive knowledge. Cavanaugh and Permutter (1982) make the point in the context of metamemory research.

> Conceptual confusion (between what a person knows and how that knowledge is used) can result in an inability to explain performance. For example, one can never be certain whether impaired performance is due to faulty or absent use of well-articulated memory knowedge or "inefficient" use of inadequate knowledge. This determination becomes crucial if one wishes to understand the relationship between knowledge and memory (p.15).

The final category of training studies identified by Campione, Brown and Ferrar (1982) addresses the process issue. These studies involve self-control training. Here subjects are instructed not only in the use of a strategy but also in how to employ, check and evaluate the strategy. In other words, subjects are explicitly trained in various executive control processes (Brown, 1978, Brown and DeLoache, 1978).

A series of studies conducted by Brown and her colleagues (Brown and Barclay, 1976; Brown, Campione and Barclay, 1979) illustrate the self-control training approach. They taught retarded and non-retarded subjects (MA 6-8 years, CA 9-11) a rehearsal strategy for recall of a list of pictures. Subjects were concurrently taught several monitoring strategies (e.g., checking and anticipation responses). Following training, children improved their performance significantly over control subjects. Further, subjects differed with respect to age on how readily they responded to training. Campione, Brown and Ferrar (1982) suggest that both the type and extent of training needed to affect performance varies with the difficulty of the task and the level of ability of the learner. The ability to benefit from instruction has been advanced as a factor critical to the concept of intelligence (Brown and French, 1979; Vygotsky, 1978; Campione, Brown and Ferrar, 1982; Resnick and Glaser, 1976).

Based on observations from self-control training studies such as those described above, it has been suggested that the executive routines underlying the use of knowledge rather than knowledge about the system itself, i.e., metacognitive knowledge, are factors underlying the critical production deficit (Brown, 1978; Campione, Brown and Ferrar, 1982; Borkowski and Cavanaugh, 1981). Campione, Brown and Ferrar (1982) summarize this position.

> ...inculcating knowledge is not the main problem. The problem is that even when the relevant knowledge is known to be available to poor learners, they experience particular difficulties in accessing and operating upon it. . . major components of intelligence are learning and transfer of skills responsible for the accretion and use of knowledge (p.435).

From these studies, it is apparent that the training of executive skills or the awareness of mnemonic processes appears to be a crucial aspect of efficient problem solving. As previously discussed, metacognitive knowledge (or more specifically in the studies quoted, metamemorial knowledge) is related (albeit only minimally using present research techniques) to performance and strategy use during strategy maintenance and generalization (Kendall, Borkowski and Cavanaugh, 1980). Furthermore, a reciprocal relation between performance and metacognition is suggested, that is, metamemorial knowledge leads to further use of memory skills which, in turn, leads to enhanced metamemorial knowledge, etc. (Flavell, 1981). Two lines of research are thus apparent: that dealing with executive processes and performance and that dealing with metacognitive knowledge (specifically metamemorial knowledge) and performance. While there seems to be little rapprochement between the two areas empirically, theoretically there has been some speculation on their relationship. Campione, Brown and

Ferrar (1982) have suggested a hierarchial relationship between the two, that is, metacognitive knowledge is learned from such self-regulatory activities as checkng, monitoring, anticipating, etc.. Similarly, Lawson (1984) argues that metacogitive knowledge is a result of reflection upon cognition which can best be characterized as an executive operation. In his words,

> ...the act of reflection involves an examination of the stream of cognition - an examination which includes analysis, evaluation of progress in terms of plans, monitoring, and modification of cognition (p.8)

Metacognitive knowledge seen in this way, results from the operation of executive processes. Alternatively, Flavell (1981) has argued that metacognitive knowledge, experiences of not knowing, confusion, etc., prompts the invocation of executive processes (e.g., checking, monitoring, selecting alternative strateges, etc.).

> The feeling that we do not understand part of an instruction is, of course, often followed by an inability to follow it correctly, provided that we do not use that feeling to instigate further attempts at understanding. On the other hand, the outcome is liable to be more successful if the feeling elicits additonal comprehension effort (Flavell, 1981, p.50).

From this perspective, metacognitive knowledge and experiences may be stored and subsequently used to cue monitoring and regulating activites of future actions. In fact the two perspectives can be viewed as two parts of an entire cycle, i.e., metacognitive knowledge or experiences may prompt executive processing which in turn generates further metacognitive knowledge.

A General Pattern of Metacognitive Development

Notwithstanding both the methodological and design limitations previously discussed, a general pattern of development has emerged based primarily on single variable studies using Flavell's taxonomy that was referred to earlier (Flavell, 1978, 1981). Typically, children become more realistic and accurate in assessing their own memory capabilities with increasing age and mental ability (Flavell, Fredrick and Hoyt, 1970; Yussen and Levy, 1975; Brown, Campione and Murphy, 1974; Levine, Yussen, DeRose and Pressley, 1978). Further, with age this knowledge becomes increasingly differentiated. Using a structured interview format, Kreutzer, Leonard and Flavell (1975) investigated a wide range of memory phenomenon of children in kindergarten and grades 1, 3 and 5 (approximately age 6, 7, 9, and 11 years). They found that while the younger children (kindergarten to grade 1) had some metamemorial knowledge, not until grade 3 to 5 did they develop a differentiated concept of memory ability, that is, memory ability varies from occasion to occasion in the same individual and differs from individual to individual in the same age group. These results are supported by earlier studies related to differing task demands and strategy use e.g., Kreutzer et al., 1975; Paris and Myer, 1981; Brown et al., 1981). Appel, Cooper, McCarrel, Sims-Knight, Yussen and Flavell (1972) found children 4 to 7 years of age did not differentiate in their use of strategies when given instructions to memorize a list versus instructions to look at a list. Tenney (1973) found similar results in children's use of categorization under variable instructions. It should be noted, however, that children as young as 3 and 4 years of age have been found to engage different, albeit very simple, strategies under variable instructions (Wellman, Ritter and Flavell, 1975; Yussen, 1974; Acedelo, Pick and Olson, 1975; De Loache, Cassidy and Brown, 1985) again reinforcing the interaction between the nature of the task and strategy use.

The Effects of Knowledge on Performance

The preceding section has dealt with methodological and conceptual issues relating to the investigation of metacognitive knowledge and metacognitive skills. It was earlier suggested that these two factors may be considered as categories under the more general rubrics of declarative and procedural knowledge, respectively. As such, they will no doubt share characteristics with these so called generic forms of knowledge; however, little attention has been focused on the clarification of these concepts. This has resulted in a lack of a common interpretation of such concepts in the literature. The issues just discussed are thus pertinent to any further consideration of knowledge related factors in the acquisition and performance of a skill.

This section will focus on the effects of knowledge on performance in terms of processing efficiency and organization. Research, particularly that dealing with the differences between expert and novice performers has demonstrated the importance of considering the characteristics of the organized knowledge base a learner brings to bear on a problem and the influence of such characteristics on a learner's activities. The critical importance of knowledge per se in memory performance was first highlighted by Chi (1977, 1978) with chess players. In a unique study in which knowledge was manipulated independently of age, Chi (1978) found adults with limited knowledge of chess were unable to memorize as many chess pieces as 10 year old children who had an extensive knowledge of chess. Further, the adults required a greater number of trials to memorize the chess board positions than the children although children could memorize fewer digits on a given trial and required a greater number of trials to learn 10 digits than adults. Knowledge in this case, was the primary determinant of performance, not age. Since then, similar results have been attained in many knowledge domains including basketball (Allard, Graham, and Paarsalu, 1980) soccer (Naus and Ornstein, 1983) and volleyball (Allard, 1980, 1982).

Perceptual - Motor Processing Efficiency and Domain - Specific Knowledge

In the area of sport, reviews of the relationship between such processing measures as reaction time, dynamic visual acuity and depth perception and resultant sport skill have been equivocal at best. In this regard, Starkes and Deakin (1984) write, "...clearly, the "hardware" components (i.e., perceptual-motor information processing components) underlying skilled performance fall short of explaining the level of expertise often seen in sports" (p.1). They go on to suggest that "...a more fruitful way of examining expertise in sport has been to look at what athletes do in specific sports and anlayze their performance in the actual tasks they do well" (p.11).

The results of their studies (and those of other researchers) suggest that skilled athletes may in fact perceive game information specific to their sport, differently than novices. In their experiment, a similar recall paradigm as that developed by Chase and Simon (1973) was used. In the work of Chase and Simon, chess players were given 5 seconds viewing time of specific game situations and then were asked to recall the positions of the chess pieces on another board. The greater the level of expertise, the better the performance. When the same task was repeated but with randomly positioned chess pieces, no difference in performace was apparent. Differences in performance were attributed to the influence of the greater knowledge in the specific areas rather than to the exercise of memory strategies as such. The same interaction between skill (reflected by level of expertise) and stimulus information i.e., structured versus random sport specific information, was found in basketball players (Allard, 1981). Allard (1981) speculates that being able to engage in the activity allows the player to develop a more extensive declarative knowledge base. As procedures of the sport are practiced, declarative knowledge about the procedures are internalized. Thus, particular structured set play situations which call for specific procedures are routinized. Also, factual knowledge associated with the procedures in the form of a specific schema, are organized, e.g., shemas for out-of-bounds plays or a press break are formed. This superior declarative knowledge base of the expert is reflected in the enhanced recall of information relating to structured game situations (as opposed to the random situations for which no schemas have been developed).

Results of a second set of experiments suggest that game structure is encoded and retrieved more efficiently by more expert players (Starkes and Deakin, 1984). Using a signal detection paradigm, volleyball players and non-players (Allard and Starkes, 1980) were asked to detect the presence of a volleyball in briefly presented slides (16 msec.) of a volleyball situation. One half the slides depicted actual game situations (structured setting), while the other half depicted non-game situations such as time-outs and warm-ups (non-structured settings). While performance was similar on the non-structued slides, expert volleyball players performed significantly more quickly on the structured slides. In a similar experiment with field hockey players (national level versus university varsity and undergraduate physical education majors), decision speeds were once again significantly faster in the expert performance (Starkes and Deakin, 1984). Following the explanation of Chase and Ericsson (1981) and Chase and Simon (1973), Starkes and Deakin (1984) suggest that a consequence of imposing organization on information is an increase in speed of retrieval and faster more reliable encoding processes, which improve with practice (although they do not make it clear whether this is a function of better organization with practice or the processes themselves becoming more efficent or indeed changes in the processes or type of organization). (It should also be noted that in neither the case of Chase and Ericsson [1981] nor Starkes and Deakin [1984] was a measure of the different organizational structures taken although evidence to be reported subsequently, (e.g., Chi and Koeske, 1983; Chi, Feltovich and Glaser, 1981) would seem to support differences in organizational structure.)

Allard and her colleagues (Allard, 1981; Allard and Starkes, 1980; Starkes and Deakin, 1984) thus entertain the view that a well integrated task specific knowledge base allows basic perceptual-motor processing units to function much more efficiently and effectively.

Organization and Structure of Knowledge

A second approach to investigations into the effects of knowledge on performance comes from Chi and her colleagues (particularily Chi and Koeske, 1983; Chi, Feltovich and Glaser, 1981). Their work has focussed on the inherent organization of the (declarative) knowledge base.

Earlier work by de Groot (1965) based on the verbal protocols of subjects, suggested that nothing in the general thought processes or search strategies distinguished master chess players from less skillful players. Following from de Groot, Chase and Simon (1973) found that both expert and novice players' knowledge of chess was represented in identical ways, i.e., patterns were inter-related by physical features (e.g., colour and proximity) and by function (e.g., defense and attack). The distinguishing feature in experts' superior recall of chess piece positions was the extent (quantity) of their chess knowledge and the manner in which positional information was chunked or grouped for recall. That is, experts had more chunks or positional patterns available for recall and each pattern contained the position of more chess pieces. Chase and Simon (1973) hypothesized that specific tactical stategies or moves were associated with each pattern and that expertise in chess depended on fast recognition of the patterns which in turn automatically cued the appropriate strategies. Thus, as noted by Chase and Chi (1981),

> The extraordinary visual memory phenomenon of the chess masters reflects not so much the perceptual nature of "intuition" but, rather, the knowledge and the organization of this knowledge that can facilitate the master's ability to have a rapid "understanding" of the chess situation (p.117).

Simon and Gilmartin (1973) developed a simulated model compatible with these results which rests on a network system of knowledge. They postulate that a large repertoire of patterns is stored in long-term memory and a mechanism, labelled a discrimination net (EPAM net), accesses them. In addition, a short-term memory of limited capacity stores the names or labels. These names or labels can be thought of as representing both an internal path through the EPAM net to the salient schema of appropriate chess moves, and the external patterns or groupings of chess pieces. Hence, the organization of the master's elaborate repetoire of chess information greatly facilitates both the encoding of perceptual information and recall of appropriate strategic play.

While similar superior recall effects by chess players have been replicated by several investigators (e.g., Charness, 1976; Gouldin, 1978; Lave and Robertson, 1979) analogous results have been found using children as experts (Chi, 1978; Lindburgh, 1980) indicating a very robust effect.

To investigate the nature of structural differences and/or changes in the organization of knowledge, Chi and Koeske (1983) compared the knowledge structures of two subsets of a domain of knowledge of a 4 1/2 year old child. One subset consisted of a list of dinosaurs better known to the subject and the other subset consisted of dinosaurs that were lesser known to the child. Before describing the study it may be useful to discuss organization changes as Chi and colleagues use the terms. The way in which the external environment is represented in memory is postulated to change in predominantly two ways (Chi and Rees, 1983). Fistly, memory structures may become increasingly more complex and sophisticated. That is, new and higher level structures are assumed to emerge. This may occur in 3 ways: 1) through increasing access to various subroutines from which view the knowledge structure is considered to have certain formal properties that persevere throughout development (Rosin, 1976); 2) it may occur through a structural reorganization consistent with the stage view of development (e.g., Piaget, 1972; Fischer, 1980); or 3) it may occur through a combinaton of the two, i.e., structural change governed by constraints. According to Keil (1980), these constraints can best be seen as certain invariant properties built into the system which, as noted by Rosin (1976), are constant throughout development. In sum then, organizational changes may take place, that is, a reorganization of existing knowledge such as the transforation of a linear structure to a tree-like structure of knowledge, and/or existing knowledge may be reorganized with the possibility of adding or deleting knowledge.

The second major change is postulated in the mode of representation. This is perhaps best illustrated by the change in children's reliance on enactive or manipulative representation, iconic representation and symbolic representation discussed by Bruner (Bruner, Oliver and

Gruenfield, 1966). In this case, structural reorganization is not inferred.

In general, in research investigating knowledge differences particularily in relation to level of skill, references to differences in the organization and structure of knowledge tend to refer to organizational changes with explicit reference to the possibility of adding or deleting knowledge. The term "structural change" Chi has reserved for this kind of change (Chi and Koeske, 1983).

Returning to the dinosaur knowledge experiment of Chi and Koeske (1983), differences in the attributes of a knowledge structure in a single subject were studied thus controlling strategy usage and capacity limitations (i.e., each were similar for both lists). Further, the knowledge structure was represented by the investigators as a network of nodes and links. Attributes of the knowledge structure were assessed by the number of links between nodes (measured by the number of properties that were mentioned across several different varieties of dinosaurs), the strength of linkages (measured by the frequency with which a particular pairing was mentioned), and the cohesiveness of the entire collection of concept nodes in the network (represented by the number of direct and indirect linkages within both subsets).

While the actual quantity of knowledge did not differ between the two subsets (this was controlled by the experimenters to some extent), the organization of the knowledge, i.e., the configuration of nodes and links, did. The semantic network of the better known list had a greater number of inter-dinosaur links, greater strength of linkages, and a greater cohesion within the network. An interesting finding was that knowing more information per se about a particular dinosaur did not facilitate its recall at a later time. A group of seven 'target' dinosaurs were selected from each subset of twenty dinosaurs. These target sets were matched on the frequency with which they were mentioned in the game from which the original linkages were derived (thus they were matched for quantity of knowledge but not quality as reflected in the distribution of linkages). In a final retention test, targed dinosaurs were not recalled to a greater degree than non-target dinosaurs in respective subsets. Thus, performance differences can be ascribed not only to differences in the quantity of knowledge (in situations where this has not been controlled, which was not the case in this study), but also to structural differences in the knowledge base (i.e., qualitative differences in the knowledge base).

A logical extension or next step in this scenerio is to ask how the organizational structure of the knowledge contributes to performance differences. Glaser (1984) succinctly encapsulates the key points.

> At the initial stage of problem analysis the problem solver attempts to "understand" the problem by constructing an initial problem representation. The quality, completeness, and coherence of this internal representation determines the efficiency and accuracy of future thinking. And these characteristics of the problem representation are determined by the knowledge available to the problem solver and the way the knowledge is organized (p.98).

Individuals represent problems in the context of the knowledge they have available for that particular context (Chi, Feltovich and Glaser, 1981; Glaser 1979; Glaser, 1984; Di Sessa, 1982). In an investigation of the categorization and representation of physics problems by both novices and experts, Chi et al., (1979) found that both groups used the same key words in the problem statement to categorize the problems but novices categorized by the structural features of the items within the problem statement, i.e., incline problems versus rotational problems. Experts on the other hand, categorized the problems according to the underlying physics principle governing the solutions. This seems contrary to the results of Chase and Simon (1973) and de Groot (1969) who suggested both experts' and novices' knowledge of chess was represented in identical ways, i.e., both patterns were inter-related by physical features and by function. In point of fact the functions of the chess pieces do not change with level of skill and are characterized by the physical appearance of the pieces which again does not change. Thus differences in representation on this basis should not be expected in this particular task. Chi et al., (1981), on the other hand, suggest that domain-specific knowledge (at least related to physics problems) is organized hierarchically. The lowest levels contain physical or structural properties and some superfical procedures for problem solving. The highest level, is organized around basic principles and procedures for their application (i.e., both declarative and procedural knowledge of a much more extensive and sophisticated nature). The more elaborate and complete nature of the knowledge base in terms of both conceptual (i.e., declarative) knowledge and procedural knowledge makes expert processing more top-down; that is the solutions to the problem are part of the expert's knowledge network and are automatically accessed from the context of the problem statement. The spartan and very superficial knowledge network of the novice lends itself to a more bottom-up approach in which the problem solver must depend on a literal interpretation of the problem statement for meager and very descriptive hints at a solution (Chase and Chi, 1981).

It would appear then that the nature of the solution to a problem is determined (in part) by the quantity of task specific knowledge a person has and necessarily by its quality, i.e., the organization and structure of that knowledge. In the same view, the particular problem solving strategies are mediated by the nature of the knowledge base. The larger the individual's procedural repertoire, the more specific strategies will be in solving a problem. The difference between the problem solving skills of the novice and expert illustrates this point.

> ...with high levels of expertise in a task domain, the problem solver becomes much more judicious in his choice of paths and may fundamentally alter his method of search ... with experience the search becomes much more selective and likely to lead to rapid success (Anderson, 1981, p.390).

Where such specific strategies are not available, the subject may fall back on more general but less powerful strategies which have previously proven successful (Siegler, 1981). It is therefore necessary to distinguish between general problem solving heuristics, strategies specific to a particular knowledge domain and task specific strategies. The context of the problem in relation to an individual's knowledge base will influence the nature of the strategy(ies) used. If a particular strategy is not used, this does not necessarily imply the absence of such a strategy. Rather the context of the problem may not have invoked the use of such a strategy or may have caused some sort of modification in the strategy. Naus and Ornstein (1983) suggest that the growing knowledge base of the child may contribute to the use of increasingly more sophisticated strategies by older children. Ornstein et al., (1975) presented 3rd, 6th and 9th grade children lists of taxonomically related materials. Half the children received the lists in random order while the other half were presented the items in blocked fashion. Congruent with the results of other studies, under both conditions, both recall and rehearsal activity improved with age. The salient finding here, however, was that while third graders rehearsed in the expected passive fashion under both presentation conditions, their recall was superior under conditions of blocked presentation.

Similar results were found by Stone et al., (1977) and Ornstein et al., (1977). That is, Ornstein et al., (1977) found that recall of sixth graders instructed to rehearse passively, was superior under conditions of strong list organization as opposed to lists vaguely organized. In conditions in which active rehearsal was present, not unexpectedly, material organized into meaningful groups for presentation was rehearsed more efficiently than that presented randomly (Stone et al., 1977).

While the material used in these studies was not controlled for meaningfulness to subjects in terms of either content or organization, it does none the less suggest that the organizational nature of the material (albeit imposed) affects both recall performance and strategy use. For tasks in which an individual has a high level (i.e., quantity) of knowledge, it can be hypothesized that recall and retention will be better and strategy use both more prolific and efficent due to the more coherent and tightly organized nature of the material (Chi and Koeske, 1983). Further, in light of the status of the child as an universal novice (Brown and De Loache, 1978), it could be expected that children's recall performance and mnemonic activity will be limited due (at least in part) to their lean knowledge base. This latter prediction has found substantial support in the literature, however, knowledge base has usually been confounded with age. In an attempt to eliminate this confounding, Naus and Ornstein (1983) investigated the nature of strategic activity using stimulus materials meaningful to adult subjects. One group of adults expert in the game of soccer and another naieve to the game were given two lists of words for rehearsal and recall. The first list was composed of words from commonly known taxonomical categories, e.g., food, vehicles, etc.. The second list was composed of words associated with the game of soccer. For this second list all the words were known by both the experts and novices but were more meaningful to the experts. No differences were found in the recall of either group for the list of common taxonomic materials. As would be expected, the soccer experts were superior in recall of the more meaningful soccer related list. In a subsequent examination of the rehearsal activity there were no differences in the number of items from the common taxonomic list included by either group in their rehearsal sets. There were also no differences in the number of items included in the rehearsal set from the soccer related list. There were however, differences in the number of items in each soccer rehearsal set which were related or common in nature. That is, experts were able to subgroup the soccer material into related categories for rehearsal. While the same number of items were included in the rehearsal set, novices were not able (or at least, did not) sub group the material into related items. Both groups did not differ in the number of category related items they included in their rehearsal from the common taxonomic list.

From these results, it can be suggested that differences in the knowledge of the stimulus material leads not necessarily to variations in the presence of general strategic activity (e.g., rehearsal) rather, it leads to variations in the form or quality of the activity. These differences would appear to be related to the inherent nature of the organization of the material.

Throughout this section, it has been suggested that both the quantity and the quality of a person's knowledge plays a crucial role in the performance of a task. Allard and her collegues (Allard, 1980; Allard and Starkes, 1981; Starkes and Deakin, 1984) entertained the view that a well integrated task-specific knowledge base allows basic perceptual-motor processing units to function much more efficiently and effectively. Chi and her collegues add the notion of differences in the quality of the knowledge base between the expert and the novice, i.e., the strength and richness of links within the knowledge network increase (Chi and Koeske, 1983; Chi, Feltovich and Glaser, 1980). Finally, differences in the representation of the problem task and subsequent differences in strategy use were suggested between experts and novices.

Partial Knowledge: A State of Transition in the Development of Skill

Up to this point, it has been emphasized that the knowledge an individual brings to bear on a task is critical to the outcome of that task. That is, performance is affected by what one already knows.

Further, the product of what one knows will vary dramatically according to the context, or environment, in which the event transpires. At the same time it was noted that two fundamental observations have repeatedly been made with regard to the development of motor skills. First, the movement patterns, or action sequences, of a novice are at first characterized by great variability. As skill is gained, performance becomes increasingly more consistent and stable such that on repeated trials the basic pattern remains essentially unchanged. Secondly, associated with the development of consistency is a concurrent development in the flexibility with which the skill can be performed. Thus, we are faced with factors which tend to increase variability and the observation that performance tends to become more stable as competence increases.

Piaget's (1971) classical notion of equilibration describes knowledge as least stable during a period of transition from naivete (or initial knowledge) to a state of more mature knowledge. Others have similarily suggested that a pattern of variability in performance reflects the underlying accumulation of knowledge (Siegler, 1983; Wilkinson, 1984; Fischer, 1980). The notion of partial knowledge has thus become an important consideration in the development of competence or skill.

Development of the Processing System

Three main models can be distinguished as representative of this state of partial knowledge. Fischer (1980) proposed that limited information processing capacity might result in a kind of homogeneity of reasoning inasmuch as the optimal level of processing of the child is at a particular level of sophistication. Flavell (1982) and Pascual Leone (1970) have offered similar views. Case (1978, 1984) argues from basically the same perspective. Case proposes that the total processing space is the same for adults as for children. With development however, the proportion of this space that must be devoted to running basic operations decreases thus freeing-up capacity for other tasks. Such a view is consistent with investigations concerning processing efficiency. Chi and Klahr (1975) reported that basic operations such as visual encoding and counting continue to develop even after they have been overlearned. Similar results of increased processing efficiency with development have been noted by other investigators (e.g., Keating and Bobbitt, 1978; Hasher and Zack, 1979).

Efficiency of the Executive Processes

The second model proposed by Wilkinson (1984), derives from a theory of partial knowledge based on a structure-process pairing. Learning is assumed to occur through a process of linking discrete modules or units of knowledge. Errors may occur either through incorrect or insufficient knowlege modules or through errors in the linking or merging of the modules. Based on this view, Wilkinson identified two categories of partial knowledge which reflect each of the error sources. Partial knowledge can be categorized as 'restricted' when certain aspects of a task are done consistently wrong or consistently right. Errors here are assumed to arise from within the knowledge module, e.g., an individual may possess a particular performance rule appropriate for some situations but which becomes inappropriate or insufficient under other circumstances. The second category of partial knowledge is that of 'variable' knowledge. In this instance performance is typically inconsistent or variable. A particular task performed correctly one time will, under identical circumstances, be performed incorrectly another time. In this instance Wilkinson suggests modular components of knowledge are retrieved from memory separately and must be linked to form a more complex action. Unstable performance can result if the process of integrating the components into a coordinated plan of action is inconsistent. Errors of this type are associated with deficiencies in an individual executive process, e.g., self monitoring. In this case an individual may have access to declarative knowledge but lack the appropriate procedural knowledge to integrate the material. In the same way, De Sessa (1982) refers to the application of 'deference links' (p. 60). Considering modules of knowledge as independent agents which become concantenated to form action or knowledge sequences (Anderson, 1982), certain orders of linkage are more likely, indeed more necessary, than others. In other words, certain modules must 'defer' to others e.g., general strategies or procedures may defer to more specific ones. Anderson (1982) suggested a process of knowledge compilation in which task-specific declarative knowledge is scrutinized by all the system's extant procedures. At this point contradictions or inconsistencies of facts or goals are identified. Once such anomalies are found, alternative strategies or procedures (if available) can be invoked (Markman, 1981). Where such strategies are not available, the subject may fall back on, or defer to, more general but less powerful strategies which have previously been validated (Siegler, 1981). Baars (1983) and Norman and Shallice (1980) have developed theoretical models incorporating this notion of deference. Knowledge may be used by specialized processors or become a part of an action schema depending on its pertinence to the system, pertinence being determined by some internal criteria of the system, e.g., attentional influences, motivational influences, priority scheduling, conflict, etc..

Wilkinson (1984) hypothesized that with restricted knowledge, performance should be stable; with variable knowledge it should be unstable. Using a series of four different types of counting tasks, each one based on an increasingly complex combination of basic counting principles as proposed by Gelman and Gallistel (1978), Wilkinson had children approximately 3 to 6 years of age perform counting skills. Each type of task included 6 different problems ranging in size from 3 to 26 items. Fitting the data to stochastic models of partial knowledge, results indicated that performance was stable across performance size and across subjects' ability or level of knowledge (measured by the number of problems done correctly), but increased as the number of cognitive components (i.e., principles) required by the task increased thus increasing the complexity of the task. Further, stability was greatest for low and high levels of knowledge, and the least for intermediate knowledge. Thus, stability during the development of a (cognitive) skill depends on both the person's level of knowledge and the complexity of the task. An additional finding was that the variability among individual children exceeded that attributable to age; however, this could be a partial artifact of a restricted age range. Wilkinson concluded that the development of (at least) skilled counting during the preschool years depends more on learning to merge and co-ordinate units of knowledge, than on acquiring the units themselves. Gelman (1978) shares this view suggesting that, "the nature of development (of counting skills), at least from 3 years of age onward, appears to be one of skill perfection and not the apprehension of new principles" (p.234).

Adequacy of Individual Knowledge Units

Siegler (1976, 1978, 1981) rather than focusing on the linking of knowledge units, has focused on the development of increasingly sufficient knowledge modules. He suggests children's problem solving strategies are rule governed, with the rules progressing from less sophisticated to more sophisticated as a function of age and learning (Siegler, 1978). To investigate the acquisition of knowledge pertinent to various scientific concepts, Siegler (1976, 1981) has developed a methodology for assessing the underlying rule structure of performance. This methodology has been applied to a number of tasks and concepts including the balance scale (Siegler, 1976), projection of shadows (Siegler and Vago, 1978) and speed, time and distance (Siegler and Richards, 1979).

The essence of the rule assessment approach is to generate a series of rules which might be used to solve a particular conceptual problem and then formulate problem types that yield a distinct pattern of answers for each specific rule, if used. The rule models predict whether children will answer each question correctly or incorrectly as well as the particular errors they will make.

Applied to one of Siegler's (1976) earlier problems, the balance scale problem, four rules were described. Children using rule I would base judgements solely on the amount of weight on either side of the fulcrum. Children using rule II would in addition consider distance whenever weight was equal. A child using rule III considers both weight and distance but, if these two dimensions are in conflict, the child resorts to guessing. Finally, children using rule IV compute torque and choose the side with the greater value. To assess children's knowledge of the balance scale concept (through the use of these rules), six problem types are presented. They are: balance problems, with equal amounts of weight equidistant from the fulcrum; weight problems, with different amounts of weight equidistant from the fulcrum; distance problems, with equal amounts of weight different distances from the fulcrum; and three conflict problems in which combinations of weight and distance dimensions come into conflict (conflict-weight; conflict-distance; conflict balance). Using this combination of rules and problem types it is possible to predict the percentage of correct answers as well as the particular errors children will make.

Basically the rule assessment approach assumes that conceptual development can be thought of as an ordered sequence of learned, partial understandings (expressed in the form of increasingly more adequate rules). Siegler (1983) suggests the 'adequacy' of these rules and their subsequent adoption by a child may be based on their perceived accuracy in solving problems. That is, if a current rule is not consistently accurate in its application, a child may well try other hunches or hypotheses. If one of these seems to reliably predict more accurately than the rule currently in use, the child will adopt this hypothesis as her new rule.

While the new rule (assuming it not to be the mature rule) will be more accurate over a wider range of circumstances, it may in fact be less accurate in certain specific circumstances (in which the old rule may have been more effective). Only when the child assumes the mature rule will performance reach a state of consistent accuracy. With Wilkinson (1984), Siegler (1983) suggests stability of performance is greatest for low and high knowledge, and the least for intermediate knowledge but for different reasons. Wilkinson (1984) points to deficiencies or errors in the linking of units of knowledge. His arguement is built on the notion of inclusion, i.e., earlier developing rules are included in later developing ones (Flavell, 1972) which may in fact apply to some of Siegler's tasks, for example, the balance scale. Here, rule II, in which both weight and distance are considered, actually subsumes and extends rule I. Children must first consider the amount of weight on either side of the fulcrum. If they perceive it to be equal, they then consider the distance of the weights from the fulcrum. Finally, the proportions of weight to distance are considered. However, Siegler (Siegler, 1983; Siegler and Richards, 1979) points to several other instances in which the initial rules used by children are not linked by inclusion to subsequently more powerful rules (e.g., rules associated with the concepts of time, distance and speed and those associated with the conservation of liquid and solid quantities). Once children recognize that the rules they are using are imperfect, they may start to integrate other aspects of the task environment in an attempt to develop new, more accurate hypotheses (Karmiloff-Smith and Inhelder, 1979; Olson, 1970). Siegler (1983, 1976, 1978) suggests that new rules do not necesarily evolve from old rules and further, encoding is a critical component in the process by which new rules are formed.

Drawing together all three models of partial knowledge, we may suggest success in performing a task is determined partly by the completeness or adequacy of individual knowledge units, partly by the proficiency of the executive processes in linking these units and partly by the development of the processing system.

The Development of Competence: Some Phenomenological Studies

One can not study learning without studying the learning of something. The next section will review several phenomonological investigations which attempt to follow the transition from naieve to expert status on specific tasks. There is a striking similarity in many of the observations of each investigation. The scenario which seems to unfold can be interpreted in light of the previous discussions.

Learning to Balance a Block

Karmiloff-Smith and Inhelder (1979) had children aged 4 1/2 to 9 1/2 years balance a series of blocks across a 1 cm. rod. Four main categories of blocks were used in which the centre of gravity was varied: category I, referred to as 'length' blocks, had weight evenly distibuted over the length of the block (i.e., the geometric centre of the block coincided with the centre of gravity of the block); category II or 'conspicuous weight' blocks, had an uneven distibution of weight over the length of the block but was easily seen by subjects;

category III, or 'inconspicuous weight' blocks, were similar to the previous category but had the weight hidden in the blocks; and, category IV, 'impossible' blocks, which could not be balanced without the application of counterweights (i.e., moving the position of the fulcrum was not sufficient to achieve a balanced state). The focus of the investigation was to observe the interplay between subjects' action sequences and the changing theories, or implicit ideas, which seemed to underlie their problem solving responses.

An invariant sequence of problem solving strategies was apparent which seemed more dependent on the absence or presence of certain knowledge structures than on age alone. That is, similar action sequences were observed in many children of the same age as well as children across different ages. The older the child however, the more quickly he/she tended to move through the sequence of strategies. The critical determinant of level of performance was the dimension of the task subjects perceived as being important to the solution and thus encoded for use.

The initial problem solving approach involved placing the block at any point on the balancing rod. Obviously this strategy was unsuccessful but such negative results triggered a change in focus for subjects from the goal of balancing the blocks to one of exploring the properties of the blocks in order to seek a way of balancing them. This entailed a strategy of attempting different balancing points and making corrections based on the weight of the falling or teetering block. Each time success was met, this information was immediately used to initiate the next trial. Preliminary success on the 'length' blocks seemed to suggest to subjects a centre balancing point and in fact, became a very robust theory for subjects to the extent that they stubbornly persisted in applying the 'geometric centre theory' as it was termed by the authors, despite negative results.

Subjects at this level were actually using a more sophisticated strategy than that used previously but they were less successful in their results. While being basically 'data-driven' by the proprioceptive feedback from the falling block, initial level subjects were successful in balancing not only the 'length' blocks but the 'conspicuous' and 'inconspicuous' weight blocks (though not the 'impossible' blocks as they could not provide the necessary counterbalance). While subjects at the next strategy level went beyond the mere fact of balancing and were recognizing something about the balancing position of the block and in this sense were conceptually-driven, they were successful with only the 'length' blocks and gave up in frustration on the others.

In terms of what was being encoded, Karmiloff-Smith and Inhelder suggested the early strategy subjects encoded the result (i.e., that the block balanced). While they were sensitive to the sensation of the block falling and used this to make subsequent corrections, they were not concerned with the means of balancing and the use of this information on subsequent trials. Subjects using the latter strategy were encoding the length dimension of the block in this case as a means to reach the balanced state. That is, the block would balance if length was equal on either side of the fulcrum. In this sense subjects had a theory on which their actions were based, even if wrongly. Contradictions to this theory were rejected as exceptions.

Subjects stuck tenaciously to this strategy but did eventually, albeit reluctantly, make some changes. In discussing what factors may precipitate such a change, the authors propose that only when subjects perceive a regular pattern of events and can extract a rule based on this pattern of invariance, are they able to consider counter examples (i.e., negative responses) as something other than exceptions (p.204). Thus when the geometric centre theory was fully consolidated and generalized in their minds, subjects were able to perceive the regularity of counterexamples and had to find some explanation for them beyond length (which, after all, was the basis of the positive results of the geometric centre theory). In this regard weight became a new and important consideration. In contrast to earlier level subjects who used weight as proprioceptive feedback, subjects at this new level began to differentiate between weight as an absolute property and weight as a force which interacts with length. Initially weight and length were used as two quite independent strategies, i.e., subjects were successful on the 'length' blocks using length and successful on the 'conspicuous weight' blocks using weight but unsuccessful on the other types of blocks. Eventually however, the two dimensions were used together producing success on the 'inconspicuous weight' and 'impossible' blocks. In the mature pattern, a refinement of the previous strategy, subjects could easily manipulate both length (by altering the fulcrum) and weight (by applying counterbalances) simultaneously.

A similar encoding arguement is proposed by Siegler (Siegler 1976; Siegler and Richards, 1979). With Karmiloff-Smith and Inhelder (1982), Siegler (1983, p.273) suggests that results which contradict expectations may well trigger the learning process; but that learning the process takes on a far different hue for younger children than for older children. Using the rule assessment methodology with the balance scale task, Siegler (1976) found children 5 years of age and 8 years of age equated for using the identical preliminary rule, derived radically different lessons from experience with subsequently more complex problems (i.e., conflict problems). Older children tended to benefit from the experience and adopted a more appropriate rule (rule III), younger children did not benefit at all and remained at rule I. Using a variant of the reconstructing paradigm developed by Chase and Simon (1973), 5 and 8 year olds were presented balance scale configurations of disks on pegs for 10 seconds. A second scale was then presented and subjects were to reproduce the original configuration of disks on the second scale. Four outcomes were possible: both weight (number of disks) and position (number of pegs) could be reproduced accurately; weight but not distance; distance but not weight; or, neither dimension could be reproduced exactly. Results showed older children who were assumed to encode both weight and distance, did produce both dimensions accurately. Younger children assumed to encode weight but not distance, produced only weight configurations accurately. Further, when trained in both what and how to encode, the pattern of encoding for 5 year olds on both weight and distance was similar to 8 year olds (although at a lower absolute level of accuracy). Finally, when retested on the balance scale task, 5 year olds also benefited from experiences in the conflict problems (although still to a lesser degree han

8 year olds). Thus, changes in encoding allowed children to acquire a new dimension of knowledge that they would not otherwise have been able to acquire. An identical pattern of results was found for 3 and 4 year olds in a similar experiment (Siegler, 1978). A strong distinction is made here between what children know and what they can learn. That is, improved encoding did not directly affect what the children knew but rather affected their ability to learn by providing conditions which were conducive to such activity. Siegler (1976) suggests a general three step view of development,

> First, knowledge is at a particular point, and encoding of particular stimuli is well adapted to the constraints of that knowledge. Second, the range of dimensions that are encoded expands, but knowledge remains unchanged. Third, knowledge grows and becomes consistent with the new encoding (p. 516).

In general however, children are less likely to know what attributes of a task would best be encoded in a particular situation even if it were part of their long term memory store (Siegler, 1983) and, further, their typically constrained experiential base reduces the likelihood of such attributes being part of their long term memory store (Brown and DeLoache, 1978). Previous discussions on the differences in organization and representation of problems between experts and novices further emphasize the relation between what is encoded and the strategy brought to bear on a particular task (and the resultant performance) (e.g., Chi, Feltovich and Glaser (1981) in physics problems and Naus and Ornstein (1983) on a soccer task).

Learning Angles of Movement

In a second phenomenological investigation into the path of learning, De Sessa (1982) observed a group of eight sixth grade students (age approximately 10 to 11 years) learn to control a computer guided graphics symbol (called a dynaturtle). The dynaturtle conformed to Newton's laws of motion and as such was dependent on an understanding (although not necessarily formal) of vector addition for successful manipulation. In a follow-up experiment similar to the first, De Sessa had a university freshman familiar with some high school and university physics, attempt to control the dynaturtle. Subjects were asked to manipulate the object (through the computer keyboard) to hit a central target. De Sessa attempted to describe a 'genetic task analysis' or learning path(s) which took subjects from the naieve knowledge state to that of being able to solve the dynaturtle task.

The observations of De Sessa in the physics problem and Karmiloff-Smith and Inhelder (1979) in the balancing problem share some striking similarities. As with Karmiloff-Smith and Inhelder (1979), De Sessa noted a remarkable similarity in initial strategies used to control the dynaturtle. Even a group of physics-naive adults reportedly showed considerable overlap at the early stages of learning with the sixth graders although they eventually progressed on the task both faster and further.

De Sessa also described subjects' actions as being driven by an underlying 'theory' of the task. The term 'theory' is used in the sense of that used by Karmiloff-Smith and Inhelder (1979, p. 208). They use the term to mean a set of underlying ideas which serve to determine or bias subsequent actions. The child does not intentionally seek to verify the theory through counterexamples but rather, comes to recognize counterexamples through repetition. The term 'hypothesis' they suggest has the connotation of intentionally seeking to verify and should be seen as distinct from having a 'theory'. Associated with subjects' theories were certain expectations of how the dynaturtle should move. When the response was in fact contrary to expectation, the negative results triggered a change to the strategy. De Sessa discusses the use of a failing strategy by one particular subject which is repeated again and again. He builds on the arguement made earlier by Karmiloff-Smith and Inhelder (1979) that such persistent repetition may reflect the strength of an old 'theory' but goes on to suggest that it more likely reflects the subject's attempt at trying the problem from a different angle so to speak. As noted by De Sessa, "attempts [to be seen] as repetitions requires a way of thinking about them as being the same (p. 45)". From the perspective of the subject, each attempt may indeed not be the same. It is through this persistent repetition that one eventually develops an invariant recognition of a particular situation or event even as the specific frame of reference changes.

De Sessa suggests that through development of an invariant recognition of an event, subjects are actually learning to focus on key features of the event, a theme already echoed by Siegler (1976) among others (Siegler and Richards, 1979; Wellman, 1983). Subjects were able to shift their focus from position as the relevant dimension to that of a rudimentary vector notion of velocity. De Sessa describes the process in terms of the consolidation of a way of viewing events which in turn allows the individual to generalize and extend a strategy. Initially subjects are limited and controlled by the specific context of their actions. De Sessa speaks of, "natural patterns of development in which context specifics might be peeled away from the abstracted ideas (p. 56)". As the ideas become more finely developed (through repeated experimentation) they become more available to participate in the explanation and be extended or generalized in their generic form to other situations.

Learning Addition Skills

Lawler (1981) also addresses this notion of context in the learning process. Over a six month period, Lawler followed the emergence of addition-related skills in a six year old subject. As in the two previous phenomenological investigations, the focus was on the impact of specific experiences on the changing theories and procedures underlying the problem solving strategies of the subject. Lawler suggests the child's world is made up of very specific modules of knowledge he calls 'microworlds', each one constructed through a number of experiences in a limited domain of activity. The subject of this investigation was described as initially having three microworlds related to counting skills but each one quite distinct from the other. For example, she displayed a 'money count' world in which calculations were done in terms of coin denomination, a 'numerical count' world in which mental calculations were done in terms of tens and counting numbers, and a 'paper count' world which dealt with columns of digits and their interactions. The way in which a counting problem was presented determined which structure was engaged. Infact some problems could not be solved using certain structures unless rephrased to fit another context. Thus, according to the context of a problem, different microworlds are activated with different solutions.

De Sessa (1982) earlier suggested that the perspective of the child in interpreting an event was crucial to the strategy used. Lawler further suggests that the external information (e.g., suggestions from the investigator) will be interpreted from that perspective and used only if it 'makes sense'. Thus, what 'makes sense' will completely dominate everything else. For example, in learning to carry a digit from one column to the next, the perspective of the subject was such that she could not see the '1' as a '10' when the number '12' was broken into a '1' and a '2'. Infact, by breaking it down this way, from her perspective, one loses '9'! A carrying rule subsequently imposed on the child, made no contact with the underlying logic of her 'paper count' microworld and was thus dismissed in favour of one of her own invention that made perfect sense to her (although limited in its usefulness).

Lawler suggests that the transition in strategies is based on the surprising congruence of two strategies (each originating from disparate microworlds). Thus, when the subject resolves a particular addition problem using one strategy and obtains exactly the same results using a different strategy, the coincidence of the results produces not only surprise, but a moment of insight. Lawler writes, "the surprising confluence of results - where none should have been expected - could spark a significant event: the changing of a non-relation into a relation, which is the quintessential alteration required for the creation of new structure (p.18)". The creation of a new structure is, in effect, the integration of two disparate microworlds into a new, more powerful microworld.

Lawler thus suggests a second instance that may trigger the transition in development to a higher level of competence - the unexpected congruence of two simple strategies (the first instance was that of contradiction discussed by De Sessa (1982) and Karmiloff-Smith and Inhelder (1979)). Even so, the underlying processes which lead to such insight from either perspective, are speculatively the same: refinement of perspectives in one microworld which in turn lead to a much more broad application of the knowledge to new experiences, are coupled with the reorganization of disparate microworlds to form a new structure. This, Lawler claims, is really the epitomy of learning.

Taking evidence from the preceeding phenomenological studies, the next section will attempt to integrate some views on a possible theoretical basis of the acquisition of skill.

A Framework for the Acquisition of Knowledge

Anderson (1982) has suggested a framework for the acquisition of cognitive skill in which declarative knowledge is directly embodied in procedures for performing the skill (procedural knowledge). When a person is initially introduced to a skill, the procedural knowledge he/she brings is often weak and/or inappropriate. Anderson suggests this procedural knowledge is modified by declarative and metacognitive knowledge derived from repeated interactions with the task. Thus, the geometric centre strategies of subjects in the Karmiloff-Smith and Inhelder (1979) investigation were eventually modified through repeated trials using the old strategies. Similarily, persistent negative results of Aristotelian based strategies on the dynaturtle provided subjects with feedback crucial to a shift in strategic activity. Anderson suggests that, with practice, the domain-specific declarative knowledge becomes embedded within the procedures eliciting conceptually-driven responses as opposed to the initial data-driven response. Again, young children in the block balancing investigation (Karmiloff-Smith and Inhelder, 1979) made adjustments once the block began to fall (data-driven) but as their knowledge of the task broadened their perception of the task also changed and actions became increasingly conceptually-driven, i.e., their prevailing theory of the task and resultant expectations as to what should happen guided their actions and feedback from the block was ignored.

Wall et al., (1985) argue from a similar perspective for the development of the conscious control of action. They suggest inate reflexes provide the procedural basis from which voluntary actions emerge. (Hasher and Zack (1979) have suggested that rudimentary metacognitive skills may be available at birth similar to the inherent nature of reflex activity.) Initial data-driven interactions with the environment provide the child with information about the world about her. Using the notion of knowledge compilation (Anderson, 1982) they observe that, "at first children's actions are mainly data-driven; however, as they increase their store of declarative knowledge about action, they begin to use that knowledge to refine existing procedural knowledge" (Wall et al., 1985, p. 40). With practice, the strategies being used in turn become embedded procedural knowledge which, instead of interfering with skilled action, actually give to it the appearance of fluidity. The notion of automaticity is often associated with this state. That is, an action sequence (or some part of it) is no longer mediated by conscious control (Anderson, 1982; Norman and Shallice, 1980; Schneider and Fiske, 1983). Actions are spontaneously and unconsciously invoked in response to the appropriate stimulus conditions. Flavell (1981) suggests that in cases where a strategy (or action sequence) is so overlearned and habitual, metacognitive processes may infact be bypassed. Only in such instances where one must once again attend to the sequence of events (e.g., when the expected result is not achieved or novel sequences are confronted (Norman and Shallice, 1980, p. 22)) need metacognitive skills be invoked and an individual become aware of her own actions.

Anderson (1982) suggests a series of procedures (or, in his words, productions) will, with practice, collapse into a simple, more efficient production. A complex action may thus be viewed as being made up of a series of discrete units. As each is mastered it may be conjoined to form a more complex task. These components may become so engrained that it eventually becomes difficult to separate them (Schneider and Fiske, 1983). At the same time, a particular action sequence may become a sub-routine in a variety of other actions or action sequences. De Sessa (1981) labels this sort of partial knowledge a form of distributed encoding (p. 59). He suggests that once a full action sequence ~~or some other~~

body of knowledge is well known and understood, the expert is able to 'break off' well used sub-routines. These, in turn, become automated and separately encoded. While they might in fact be redundant (as they can be derived from first principles), De Sessa maintains such special cases are important to fluid expert performance.

Another slightly different example of distributed encoding, one more typical of the novice, can be described in which a particular sub-routine or routine may be appropriate to more than one context. The expert may 'see' the multiple applications but the novice may fail to make the connection. De Sessa (1982) elaborates:

> When an expert says a novice does not really understand an idea, it might well mean that the expert knows a context in which the student might not be able to apply the idea i.e., the student lacks a way of interpreting the context so as to see the relevant idea (p. 60).

In sum then, it is suggested that repeated interactions with the environment provides one with the basis with which existing procedural knowledge can be refined. Once these procedures are well known they become embedded action sequences which, under the appropriate environmental conditions, can be automatically accessed either in whole or in part.

Conclusion

Throughout this chapter, several points have come to light and need to be taken into consideration in investigations of knowledge and its influence on performance. First, motor development is concerned with action. As such, investigations into the development of skillful activity must employ tasks characterized by both cognitive and motor components. Secondly, it is evident that performance is affected and molded by an array of external factors. Brown (1982) among others (Jenkins, 1979; Flavell, 1981), makes a strong case for the multidimensional consideration of task-related factors in the analysis of performance. Wellman (1983) makes a similar arguement from a developmental perspective. Thirdly, discussions related to the concept of metacognition and its interpretation in terms of both performance and development, highlight the difficulty of defining and understanding the complex role of knowledge-related factors. At the same time it emphasizes the need to focus attention on this area. In the same vein, labeling different categories of knowledge is as yet still somewhat arbitrary; however, it may provide some general consensus for the interpretation of knowledge-related factors across investigations. Fourthly, performance must be considered within the specificity of a particular task domain. While some attention has been given to general strategies and processes (c.f. Sternberg, 1985), it is clear that task specific knowledge, in terms of both its quality and quantity, plays a crucial role in the way in which an individual chooses to execute a task and thus in the development of skillful performance. Finally, both age and experience must be considered as critical factors in the development of a skill.

Exploratory studies of a descriptive nature are needed. The effects of manipulating task factors not only in a single performance, but with different age groups and with single subjects over time, need to be investigated. Changes in the knowledge base as a result of different task interactions also need to be studied on the same basis.

CHAPTER 3

METHOD AND RESULTS

Experiment 1

In this chapter, a series of four experiments will be described, each one separately. Taken together, the experiments attempt to investigate the dynamic interaction of subjects' extant declarative and procedural knowledge regarding the nature of the experimental task, and how that knowledge is used under variable conditions as well as the resultant effect such action has on the original knowledge base.

Methodology

The methodology for this investigation was suggested by Siegler's (1976) rule assessment technique for assessing knowledge. The rule assessment technique is based on the assumption that cognitive development can be characterized as the acquisition of increasingly more powerful problem solving rules with age (Siegler, 1976). Evidence of these rules is assumed to reflect the child's knowledge state. Siegler (1978) suggests that the child makes a series of binary decisions in solving a problem and that these decisions are based on rules. To the extent of her knowledge base, a child will be able to appropriately use certain rules or procedures in the decision making process; however, once the level of difficulty of the problem exceeds the bounds of the knowledge base, decisions will be based on an inappropriate application of those rules. A positive correlation between the ability to use each rule and age should suggest a developmental pattern. Also, to the extent that there is a relation between the declarative knowledge and procedural knowledge (as defined in the context of these experiments), certain knowledge-base related patterns should emerge along with the developmental patterns. That is, both within and between age categories knowledge based patterns should emerge. Specifically, the scope of the declarative knowledge-base and its expression might influence the procedural knowledge of the children irrespective of age and would be reflected in a particular response pattern which might not be congruent with the developmental one.

Briefly, the procedure involves the experimentor generating rules (through a task analysis) to solve a specific problem. Problem types that will yield a distinct pattern of answers based upon the rule used are then formulated. The pattern of errors is used to infer which rule has been applied.

While any methodology is limited by the investigator's initial hypothesis (such is the nature of scientific inquiry (Kuhn, 1962)), Siegler's procedure has been criticized as being too deterministic. That is, the rules that are used may be inherent within the methodology. Strauss and Levine (1981) have suggested that the choice of both the task and the format (i.e., forced-choice judgements) dictates that certain rules be used. If both a free choice format and different tasks were used, they assert that different rules would most probably arise. These points are certainly acknowledged by Siegler (1981) and are taken into account by the versatile and flexible application of the methodology in providing convergent evidence of rule use (e.g., Klahr and Robinson, 1981; Siegler, 1981; Siegler and Richards, 1979) On the other side of the issue, some criticism has been leveled against methodologies which use an unconstrained framework (e.g., Piagetian) in which subjects are free to determine their own solutions. It is suggested that results of such investigations may be confounded by factors associated with cognitive style (Neimark, 1975).

The methodology used in this investigation combined both constrained and unconstrained components. The second and fourth experiments involved forced choice judgements as well as an open-ended estimation of distance. In the first and third experiments, subjects were required to actively participate in seeking a solution to the problem. The initial experiment was directed towards measuring predominantly procedural knowledge in a simplified task in order to monitor perceptual ability in subjects. The second experiment was directed towards measuring mainly ~~the~~ declarative knowledge of the subjects (i.e., knowing what); the third experiment was directed towards measuring mainly the procedural knowledge of the subjects (i.e., knowing how) and the fourth experiment was directed towards measuring any changes in the declarative knowledge from experiment 2. Experiments 2 and 4 also measured the accuracy of subjects' predictions (i.e., metacognitive skill).

It should be noted that the rules that have been derived for these experiments can be considered logical rules. While they may not necessarily be psychological rules, they do in fact logically constrain the task (Kiel, 1980). That is, each subject may rationalize the appropriate movements of the experimental instrument (to be described under 'The Task') in a slightly different fashion; however, no matter what form they take, in the final analysis the procedures must conform to the 'rules' generated by the investigator in order for the task to be successfully executed.

Sample

A total of 72 female subjects participated in the study. Eighteen subjects were selected from each of four age categories. Those whose birth dates fell between January 1, 1978 and December 31, 1978; January 1, 1976 and December 31, 1976; January 1, 1974 and December 31, 1974; or January 1, 1972 and December 28, 1972 were included in the pool of 5, 7, 9 and 11 year old subjects respectively. Full scale IQ scores as measured by the Primary Mental Abilities Test or the Canadian Lorge-Thorndike Test were within the normal range (i.e., 85 - 115). These tests were done as a normal part of school procedure. Selection of a pool of all subjects meeting the age and IQ criteria was done by the principal of the school. After questioning, those subjects acknowledging prior experience with tasks highly oriented towards the experimental task (e.g., ice hockey, billiards and computer games) were excluded. Random selection of the subjects to be included in the study was then done by the investigator.

Three schools in close geographical vicinity within the Edmonton Public School System were used. Subjects with known neuromuscular, physical, sensory, or behavioural disorders which could preclude manipulation of the equipment were excluded. All subjects were right hand dominant.

Parental permission was obtained through either a permission or non permission form (see Appendix A).

The Task

The task involved rolling a 3/4 inch steel ball down a 15 inch chute such that the ball would rebound directly off the side wall of the box and hit a target square to the back wall (refer to Figure 1). The chute could be moved laterally across the base of the box.

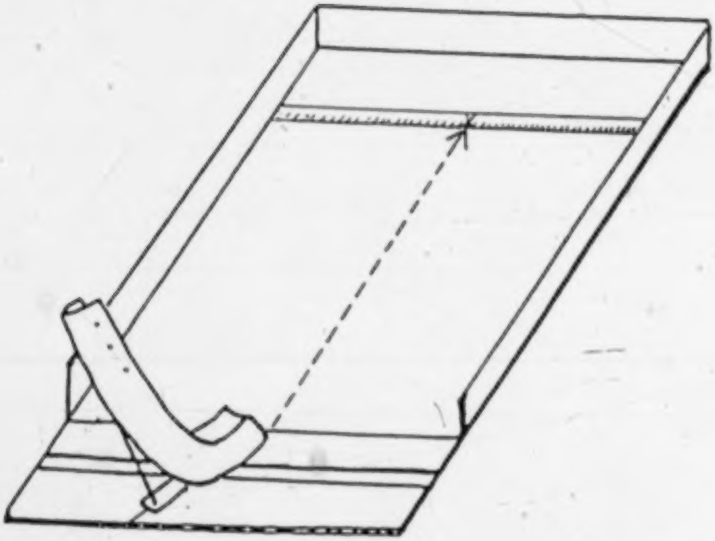

Figure 1 . Schematic diagram of equipment illustrating the criterion task.

If the ball missed the target, the subject had to know (at least in relative terms)in which direction the shute should be moved to make the correction (refer to Figure 2). This information may be expressed in the form of a rule.

> If the ball travels to the right of the target, then move the chute to the left .
>
> If the ball travels to the left of the target, then move the chute to the right .

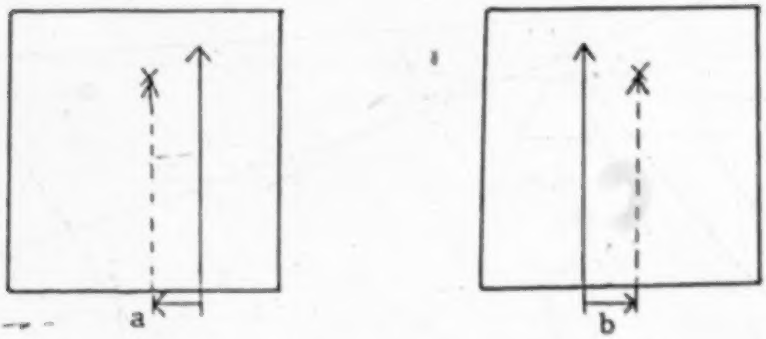

Figure 2 . Movement of the chute; a) ball rolls to the right of the target, move the chute to the left; b) ball rolls to the left of the target, move the chute to the right. (Continuous line represents initial path, broken line represents corrected path.)

Apparatus

The equipment consisted of a 3 X 4 foot piece of 3/4 inch chipboard with 1 inch chipboard on three sides (refer to Figure 1). The surface of the apparatus was finished in white arborite to minimize frictional forces and diminish environmental cues subjects could use when aiming at the target. A 15 inch stainless steel chute, constructed at an angle of 55 degrees off the vertical, was used to project a 3/4 inch steel ball. The chute was lined with 1/16 inch rubber in order to eliminate all but forward spin on the ball as it descended the chute. The ball rested on a metal pin inserted through two holes 8 inches from the top of the chute, and was released by withdrawing the pin. The pin was released by the experimenter to ensure consistency in the release. This release mechanism was used to remove as much of the motor component from the task as possible.

The chute was mounted on a mitre angle and could rotate through 120 degrees. The base of the mitre angle rested in a dado groove allowing the entire apparatus, i.e., mitre angle and chute, to move across the width of the board. The chute could thus rotate in an angular fashion and move laterally across the board. Angular rotation was measured using a protractor on the mitre angle and lateral position was measured from a tailor's tape measure glued to the back of the edge of the base board. A fine metal pointer projected from the base of the chute to the tape measure. An opaque piece of plastic projected over the mitre angle and a piece of aluminium projected over the tape measure such that subjects could not derive cues from the measurements in making any of their decisions.

A piece of white adhesive tape was placed laterally across the board, one foot from the back wall. Contrasting black lines were marked on the tape every 1/4 inch. This was done so that the path of the ball relative to the target could be clearly picked up by video for measurement purposes.

The board was kept level by adjustable feet on the bottom of the base board and by use of a carpenter's level.

Procedure

Prior to initiation of experiment 1, each subject was shown the path of the ball as it rolled out of the chute. No target was used and the ball rebounded off the back wall. This procedure was repeated three times in order to confirm to subjects that the ball did indeed follow a 'true' path.

Each subject was then required to participate in a primary task to screen her ability to manipulate the chute. Subjects were required to line the tip of the chute up with a mark on the board by moving the chute laterally along the board such that the lip of the chute touched the marker. Metric measurements were made of the accuracy of these movements. This was repeated for three targets - one to the right hand side of the board, one to the left and one in the middle. Those subjects who varied more than 1/4 inch from each target were to be eliminated. No one was eliminated from the study on this basis.

This experiment was designed to determine the appropriateness of the task to the age range selected for the study. While the preliminary tasks made it clear subjects were able to effectively manipulate the chute, the experimental task itself had to be one subjects of each age group could successfully perform. Thus, in this experiment, the basic criterion task was presented to each subject.

The chute was initially positioned to the far right of the board. The angle of the chute (controlled by the mitre angle) was set at 60 degrees to the right of the vertical and not changed throughout the experiment. Subjects were told that they were to position the chute such that the ball, when released, would hit the target directly, i.e., it could not hit a wall first. Subjects were each given up to 10 trials to hit the target. If a subject hit the target prior to the tenth trial, each trial subsequent to the hit was recorded as zero error. The chute was not repositioned to the far right between trials. No time restrictions were placed on subjects' activities. When the chute was positioned to the satisfaction of the subject, the principal investigator pulled the pin to release the ball. (The principal investigator always released the ball to ensure consistency.) Measurements were taken from the tailor's tape attached to the front of the board. This measurement reflected the position of the chute horizontally across the board. The tailor's measure was directly comparable to a parallel line drawn through the target. As such, it was also a measure of the distance between the path of the ball and the target.

Six targets were used all placed on the same horizontal plane two inches apart. The pattern of targets is shown in Figure 3. Only one target was visible at a time. Target presentation was digram balanced such that every target was followed by and preceeded by every other target. No feedback was given to subjects with regard to movement directions, accuracy, etc. by the investigators. Only the actual path of the ball could be used by subjects as direct feedback.

This resulted in a 4 X 6 X 6 X 10 (Age X Order X Target X Trial) design with repeated measures on the last two factors.

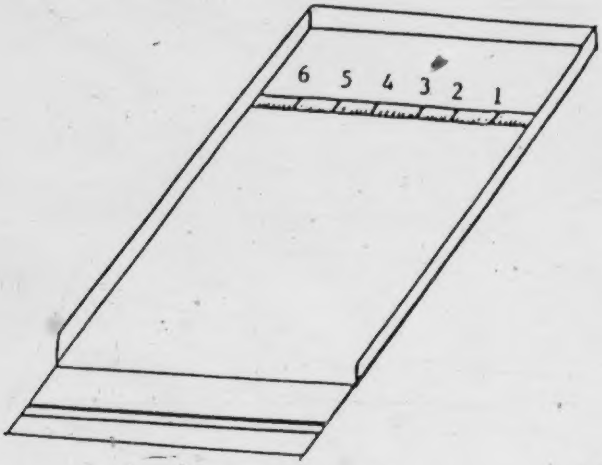

Figure 3 . Placement of targets for experiment 1.

Performance on the Direct Aiming Task: Results

The results will be discussed from two perspectives. First, task factors which had an effect on performance will be analyzed through the results of the analysis of variance. Subjects will then be classified by degree of knowledge and the data will be analyzed in terms of developmental trends related to that knowledge.

Task Factors

The dependent variable was subjects' error scores calculated as the distance (in inches) between the actual path of the ball and the target. Differences in group performance were analyzed using a 4 x 6 x 6 x 10 (Age x Order x Target x Trial) analysis of variance with repeated measures on the last two factors. Significant main effects for age, F (3,48) = 7.22, p < .001, target, F (5,240) = 19.13, p < .001 and trials, F (9,432) = 34.16, p < .001 were obtained as well as a significant age by trial interaction, F (27,432) = 5.13, p < .001 and order by target by trial interaction, F (225,2160) = 1.47, p < .001 (refer to Table 1). A similar pattern of results was found using the more conservative Greenhouse Geiser procedure. Post hoc analyses on the means were done using Scheffe's tests.

As was expected, significant developmental trends were apparent with error scores decreasing as age increased. Five and seven year olds tended to show similar performance characteristics as did the 9 and 11 year olds although significant differences were noted only between the 5 year olds and the two oldest groups (i.e., 9 and 11 year olds). Also as expected, initial trials, particularly the first two, were used by subjects to orient themselves to the proper directional movements and were thus more errorful than subsequent trials which were used to refine the aim. This was particularly true for the 5 year olds.

In general, performance accuracy increased with both age and the number of trials. That is, subjects' error scores decreased with both age and practice. Further, as age increased, less practice was needed (i.e., fewer trials) to attain the same relative accuracy. For

Table 1

Summary Table of F-Ratios for Direct Aiming Task

Part of Model	Sum of Squares	Degrees Freedom	Mean Squares	F Ratio	Probability
A[a]	116.73	3	38.91	7.22	0.001*
O[b]	20.70	5	4.14	0.77	0.576
AO	33.00	15	2.27	0.42	0.964
S - within groups	254.40	48	5.38		
T[c]	165.45	5	33.09	19.13	0.001*
AT	25.05	15	1.73	0.96	0.492
OT	42.00	25	1.68	0.97	0.507
AOT	141.75	75	1.89	1.09	0.309
TS - within groups	415.20	240	1.73		
Tr[d]	297.81	9	33.09	34.15	0.001*
ATr	133.92	27	4.96	5.12	0.001*
OTr	37.35	45	0.83	0.86	0.724
AOTr	118.80	135	0.88	0.91	0.736
TrS - within groups	414.72	432	0.96		
TTr	18.00	45	0.24	0.54	0.994
ATTr	30.80	135	0.88	0.91	0.736
OTTr	146.25	225	0.65	1.47	0.001*
AOTTr	290.25	625	0.43	0.96	0.731
TTrS - within groups	950.40	2160	0.44		

[a]Age, [b]Order, [c]Target, [d]Trial

* $p < .001$

example, as shown in Table 2, after only one trial, the average error for 11 year olds was 0.049 inches (M_1 = 0.337, M_2 = 0.049). The same approximate error score was reached by 9 year olds on the third trial (M_2 = 0.280, M_3 = 0.078), by 7 year olds on the ninth trial (M_8 = 0.124, M_9 = 0.087) and by 5 year olds on the tenth trial (M_9 = 0.138, M_{10}= 0.011). Thus, the older subjects were able to use the information gained in previous trials more efficiently.

The overall size of the error scores as reflected in table 2, indicates the ease with which all subjects could perform the task. As noted in the procedure, this task was used to observe subjects' motor responses in adjusting the chute on a very straight forward application of the rules. That is, if the ball rolled past the target to the right, the position of the chute was corrected with a movement to the left and, vice versa, if the ball rolled past the target to the left, the position of the chute was corrected to the right. Subjects very easily made the appropriate corrections in both size and direction such that, by the tenth trial all age groups were performing at approximately the same level.

While the overall task was fairly easy for the subjects, some targets presented in a particular order were more difficult during the first two trials. This was particularly true for the more distant targets

Table 2

Mean Error Scores (in inches) for each Trial as a Function of Age

	Age (in yrs.)			
Trial	5	7	9	11
1	1.922*	0.692	0.774	0.337
2	1.056*	0.297	0.279	0.048
3	0.460	0.169	0.077	0.056
4	0.291	0.135	0.034	0.006
5	0.363	0.132	0.030	0.002
6	0.263	0.151	0.027	0.008
7	0.176	0.123	0.020	0.002
8	0.136	0.124	0.009	0.000
9	0.137	0.124	0.001	0.000
10	0.010	0.037	0.000	0.000

*$p < .001$

relative to the start point of the chute (the chute was returned to the far right of the board between targets) when they were presented early in the trials. The increased difficulty of the task may have diminished subjects' ability to pick out key cues in making error corrections, for example the ratio of movement in the chute to lateral displacement of the ball as it rolled down the board. Such information would be more critical to the targets to the left of the box. This relationship is reflected in the order by target by trial interaction (see Figure 4). In order to tease out the interaction, targets were grouped into an easy and a difficult category according to results of the Scheffe post hoc tests. The difficult targets were largely those to the left and the easy targets those to the right of the box. Trials 1 and 2, 3 and 4 and, 5 through 10 were also grouped using the same criterion. The order of presentation did not seem to suggest such an intuitively appealing rationale for grouping although it would appear the most difficult order was that with the most difficult tasks in the initial positions. However, it was the interaction of a difficult order with difficult targets during the first two trials that caused subjects the most difficulty.

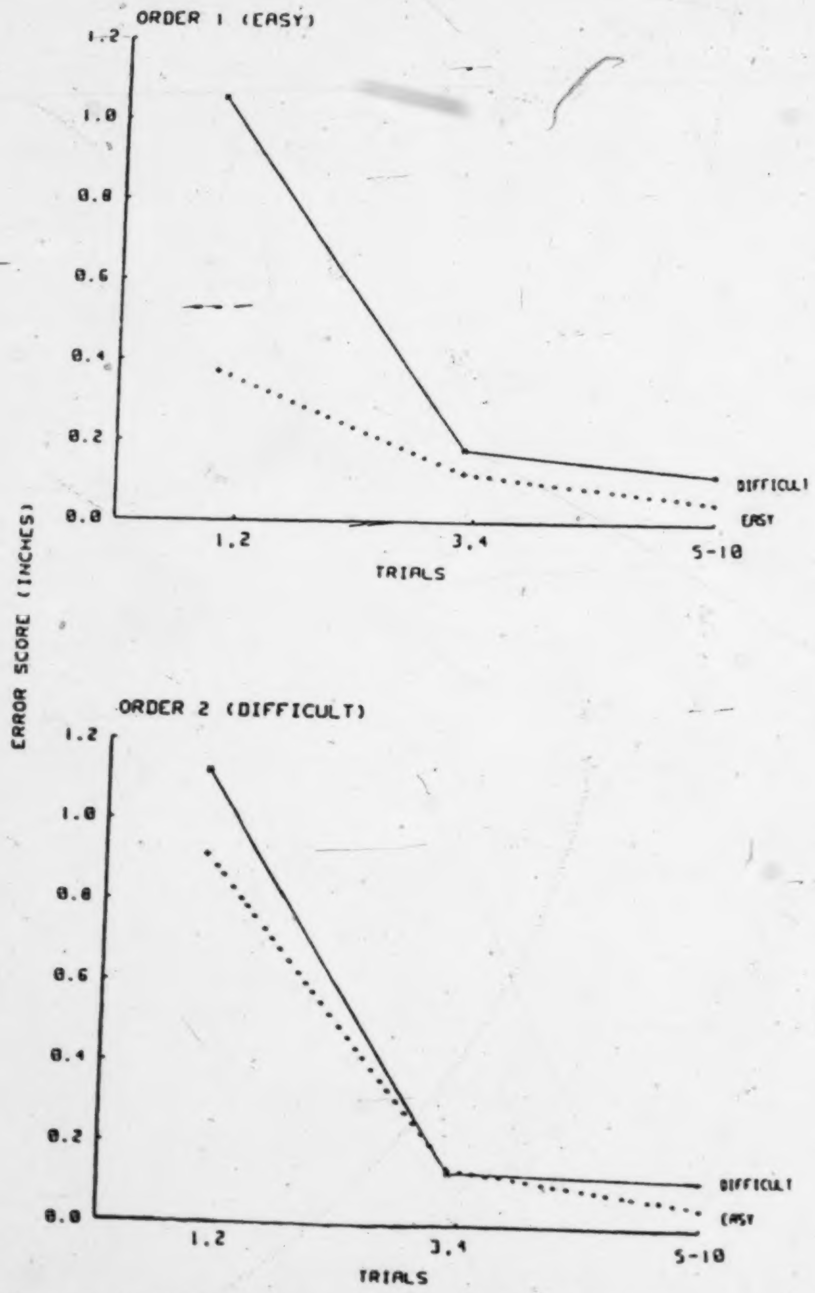

Figure 4. Mean error score on targets (grouped by difficulty) as a function of trials (grouped by difficulty) under different orders of presentation (grouped by difficulty).

Knowledge-Performance Categories of Subjects

A crucial assumption in this investigation is that the performance error score of the subjects is a direct reflection of their underlying procedural knowledge-base on this task. In other words, the knowledge categories computed for the task may also be thought of as performance categories. Knowledge categories were thus developed based on the size of the error scores (i.e., subjects' accuracy). Error scores on each trial were summed across all six targets for each subject separately. The Root Mean Square Error referred to as E (Henry, 1975; Schmidt, 1982), was calculated using the following formula:

$$E = \sqrt{\frac{\sum_{i=1}^{n} (X_i - T)^2}{n}}$$

where X is the score on Trial , T is the target, and n is the number of trials each subject performed.

The frequency and distribution of E was calculated for trials 1, 2, 3, 6 and 10. Such a series of trials was used to reflect the learning going on particularly in the first three trials. Three knowledge-performance categories were then determined for each of these trials based on the error score at the 33.3 and 66.7 percentile points. Actual boundary figures for the knowledge-performance categories are found in Appendix B.

Subjects within all age groups were then classified as being low knowledge, medium knowledge or, high knowledge for each trial (i.e., trials 1,2,3,6 and 10) in relation to the total group depending upon their error scores. As was pointed out earlier, differentiating between declarative and procedural knowledge is difficult in practice. It is suggested, at least from a conceptual stand point, that the predominant form of knowledge being tapped in this experiment is procedural.

Clear developmental trends are evident in the knowledge classification data as presented in Table 3. A preponderance of 5 and 11 year olds were classified as low and high knowledge respectively, particularily in the early trials. Seven and nine year olds were classified in the transitional middle knowledge group in the early trials. It may be suggested that performance on the second trial best reflects the status of subjects' knowledge-base coming into this task before any learning has taken place through subsequent trials. (Trial one may be considered a 'blind' trial to which appropriate knowledge-based rules are applied to correct any errors.) The greater variability reflected in 5 year old subjects' fluctuation between the low, medium and high

Table 3

Distribution of Subjects by Age and Trial Over Knowledge Categories

		Age			
Trial	Category	5	7	9	11
1	L	13	6	4	2
	M	3	9	7	5
	H	2	3	7	11
2	L	12	6	5	1
	M	6	5	8	5
	H	0	7	5	12
3	L	13	8	3	1
	M	3	3	10	7
	H	2	7	5	10
6	L	8	5	3	0
	M	0	0	0	2
	H	10	13	15	16
10	L	5	3	0	0
	M	0	0	0	0
	H	13	15	18	18

L = Low, M = Medium, H = High

knowledge-performance categories indicates the greater number of orienting trials needed by this group. Further, the lack of such variability in the 11 year olds as well as their total placement in the high knowledge group some where between trial 6 and 10, reflects the ease with which they achieved the targets. While showing somewhat more variability in the number of subjects fluctuating between categories, nine year olds were also categorized in the high knowledge group some where between trials 6 and 10. Very slight developmental trends are evident in the tenth trial but, by and large, all age groups were able to achieve the targets.

The categorization of subjects, particularly on trial 10, coupled with earlier results indicating the achievement of very accurate aiming in the task, indicates that the basic experimental task is indeed appropriate for all four age groups. That is, all four age groups are able to perform the task successfully. This suggests the presence of a level of motor competence necessary for manipulation of the chute in a very refined fashion and a level of cognitive knowledge sufficient to interpret the task correctly.

Having determined the appropriateness of the task for subjects, it is now possible to manipulate factors within the task in order to further investigate changes in performance due to age and those that can be ascribed to level of knowledge within and between age groups.

Experiment 2

With the results of the initial experiment in hand, the second experiment was designed to assess subjects' combined declarative and procedural knowledge of essentially the same task as that of experiment 1. It was assumed that if subjects could accurately and consistently predict the path of the ball under variable placements of both the target and the chute, they must have a knowledge of the underlying principles which determine the ball's path as well as the procedures necessary to apply those principles. Evidence of the presence or absence of this declarative and procedural knowledge was assessed through subjects' predictions of the path of the ball in terms of a) the direction of the prediction (i.e., above, below or, hit) and, b) the distance between the predicted path of the ball and the actual path of the ball.

Sample

The same subjects used in experiment 1 were used in experiment 2.

The Task

The experimental task was based on the one used in experiment 1. Again, a steel ball was rolled down the chute; however, in this experiment, the ball was required to rebound off the side wall of the box and hit a central target as shown in Figure 5. While the perceptual requirements in judging distances and lining the apparatus up with a target are common to the tasks of both experiments and the underlying rule structure is essentially the same, there is an increase in the task demands of the experimental task of experiment 2. In it, subjects must line the chute up with an indirect unmarked target (on the sidewall) and make adjustments based on this target. The exact nature of the effect of increasing the demands is not crucial at this point (i.e., whether the demands are additive or multiplicative in nature). What is of interest here are changes in the procedural knowledge. For those subjects able to skillfully handle the first (direct) task, increasing the task load (keeping other factors constant) will provide a situation in which problem-solving skills will be required and in which it will be possible to observe variation in the procedural performance (relative to the associated declarative and procedural knowlege-base of the children in experiment 1).

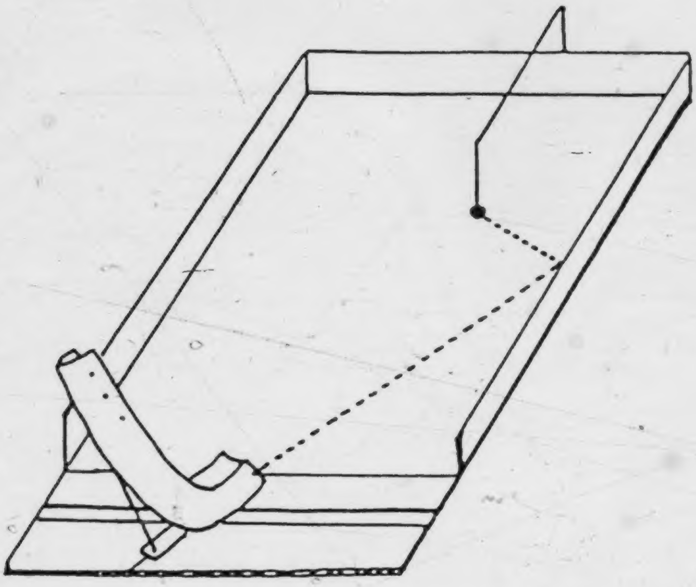

Figure 5 . Schematic diagram of apparatus illustrating the criterion task.

In this experiment, if the ball missed the target, the subject had to know (at least in relative terms) where to move the contact point on the side wall, in order for the ball to eventually hit the target, i.e., further away from the base (up) or closer to the base (down) (refer to Figure 6). Thus, the information may be expressed in the form of two rules.

> If the ball travels above the target, then the contact point on the side wall should be lowered .
>
> If the ball travels below the target, then the contact point on the side wall should be raised .

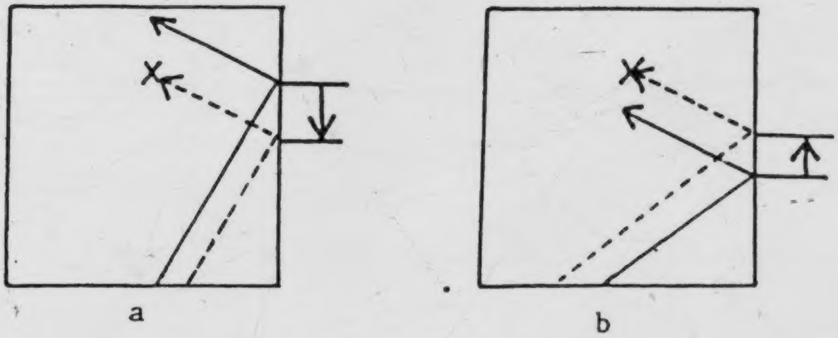

Figure 6 . Movement of the side contact point; a) ball rolls above target, move contact point down, b) ball rolls below target, move contact point up. (Continuous line represents initial path, broken line represents corrected path.)

The point of contact was controlled through manipulations of the chute. The subject therefore had to know the consequent directional effect of each manipulation of the chute. (The rules as stated here assume a right wall contact point; however, if the left wall were used, the direction of movement of the chute would be reversed. A right wall contact point was always used in this series of experiments.) The lateral manipulations of the chute may be expressed as rules (refer to Figure 7).

> A lateral movement to the right causes the side wall contact point to be lowered .
>
> A lateral movement to the left causes the side wall contact point to be raised .

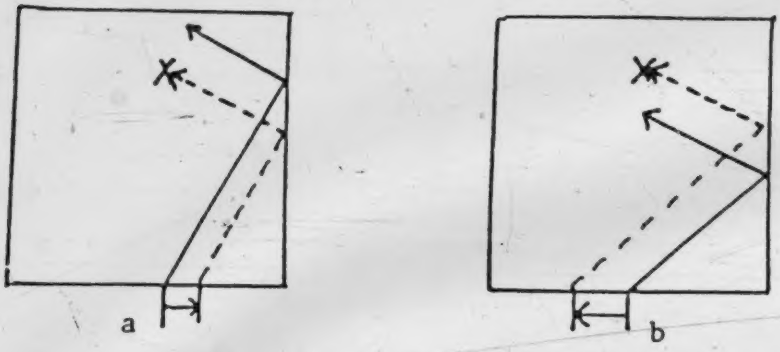

Figure 7 . Lateral movements to adjust contact point; a) a lateral movement to the right lowers the contact point, b) a lateral movement to the left raises the contact point. (Continuous line represents initial path of the ball, broken line represents the corrected path.)

In general terms, a lateral movement in the direction of the contact wall will cause the contact point to be lo~~wered and~~ thus, the rebound path of the ball off the side wall will be lowered. A lateral movement away from the contact wall will cause the contact point to be raised and the resultant rebound path of the ball off the side wall will be raised.

Apparatus

As seen in Figure 5, the apparatus was essentially the same as that used in experiment 1; however, the central target was a small bell hung by a thread from a wooden boom attached to the rear of the back wall. Several brackets were placed on the back wall such that the target position could be changed. Target positions were also changed by altering the position of the bell hanging from the boom. Small nics were cut in the boom to ensure consistent placement. A piece of white tape was also placed vertically down the board such that one edge intersected the target position (this piece of tape replaced the horizontal piece in experiment 1). The tape was moved as the target was varied. It thus represented a vertical line between the front and back of the box on which the target rested. Apart from ensuring accurate measurements, it helped to orient subjects in predicting the path of the ball relative to the target.

Procedure

The chute was positioned such that the ball would rebound off the right side wall and hit the target. Subjects were shown individually, that the ball would in fact hit the target. A piece of coloured chalk was used to mark the position of the chute on the board at this point. In this way, subjects should (could) have known that the ball would hit the target when the chute was lined up with the coloured chalk mark.

Four variations in which the lateral position of the chute was manipulated (angular position was maintained at 60 degrees) were shown to each subject individually. Each manipulation produced a missed target either above or below (as in Figures 6 and 7); however, at no time was the ball allowed to roll down the chute. This was done to prohibit feedback. Two instances of each variation were given - a near miss and a far miss (Figure 8). Two catch trials in which the ball would hit the target were also included. The rationale for including two catch trials stems from there being two basic categories of misses - above and below, and two instances of each (near and far). The catch trial was seen as a third category of which two instances would be necessary to keep the probability of occurrence unbiased (i.e., there was a 33% chance the ball would roll above the target, a 33% chance it would roll below the target, and a 33% chance it would hit the target). After viewing each variant, subjects were first asked to predict where the ball would go based on a five category scale: a) hit the target (H), b) roll far above the target (AF), c) roll just above the target (AN), d) roll far below the target (BF) or, e) roll just below the target (BN). (It was established prior to the experiment that subjects understood each of these categories by having them point out the relative position of each on the board. Further, instructions were repeated prior to each trial.) Subjects were then asked to draw on the board, the path of the ball relative to the target. (A chalk line was used and wiped off after each trial.) The distance between subjects' estimates of the path of the ball and the actual path of the ball (previously determined by the investigators) was calculated.

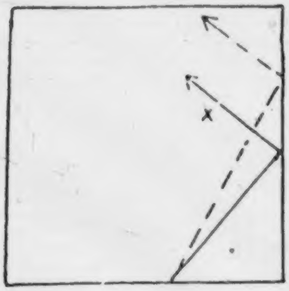

Figure 8 . Near and far misses of the target.

This procedure was repeated for six different targets. Figure 9 illustrates the placement of the targets. Targets were altered by changing both the lateral position and angular position of the chute. Subjects stayed in the same order as they were in the first experiment. A total of 36 problems were presented to each subject (4 lateral movement problems repeated for 6 targets, plus a total of 12 catch trials). More specifically, each subject received the following problems:

(6) above near
(6) above far
(6) below near
(6) below far
(12) hits (i.e., 12 catch trials)

Presentation order of the conditions was digram balanced such that each condition was preceeded and succeeded by every other condition.

Thus, the research design was a 4 x 6 x 6 x 6 (Age x Order x Target x Condition) factorial design with repeated measures on the last two factors. From the measurements taken it was possible to determine a) the predicted category of error (declarative knowledge) made by the subject when predicting the path of the ball, i.e., above the target, below the target or, on the target and, b) the error in subjects' predictions of the path of the ball relative to the actual path of the ball had it been released from the chute (measured as a metric unit, i.e., numbers as opposed to categories).

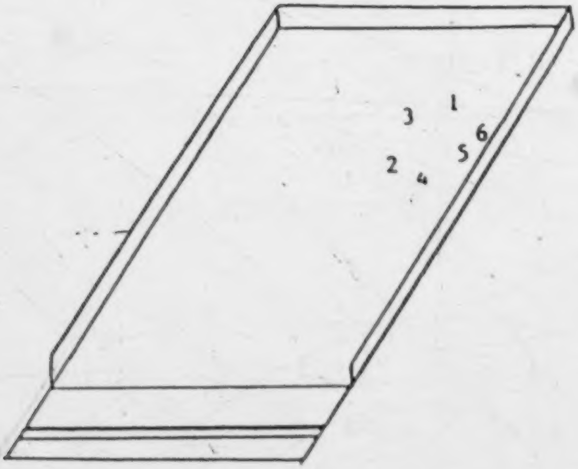

Figure 9 . Placement of targets for Experiment 2.

Performance on the Prediction Task: Results

As in the first experiment, task factors will first be analyzed through the results of the analysis of variance. Subjects will then be classified by degree of knowledge and analyzed in terms of developmental trends related to that knowledge.

Again, the dependent variable was subjects' error scores this time measured as the difference between subjects' prediction of the path of the ball and the real path of the ball. Differences in group performance were analyzed using a 4 X 6 X 6 X 6 (Age X Order X Target X Condition) analysis of variance with repeated measures on the last two factors. The analysis was repeated twice using the dependent variable calculated in two separate ways. In the first instance, categorized data was used. Subjects predicted the potential path of the ball based on the following categories: the ball could roll a) far above the target (AF), b) above but near to the target (AN), c) directly to the target and hit it (H), d) below but near to the target (BN) or, e) far below the target (BF). Each category was given a numerical code (AF=1, AN=2, H=3, BN=4, BF=5). Subjects' error scores were then calculated as the difference between their prediction of the path of the ball and the actual path the ball would have taken if released from the chute. For example, if a subject predicted that the ball would roll below near to the target but in fact it would actually have rolled above near to the target, the score was coded as a 2 (i.e., 4 - 2 = 2). The dependent variable was also

Table 4

Summary Table of F-Ratios for Predictions in the Indirect Aiming Task Using Category Data

Part of Model	Sum of Squares	Degrees Freedom	Mean Squares	F Ratio	Probability
A[a]	64.32	3	21.44	4.79	0.005**
O[b]	2.35	5	0.47	0.10	0.990
AO	52.65	15	3.51	0.78	0.686
S - within groups	214.08	48	4.46		
T[c]	14.75	5	2.95	6.35	0.001*
AT	13.20	15	0.88	1.91	0.023**
OT	16.50	25	0.66	1.42	0.091
AOT	45.75	75	0.61	1.33	0.055
TS - within groups	110.40	240	.46		
C[d]	297.81	5	0.18	0.52	0.756
AC	133.92	15	0.40	1.41	0.316
OC	37.35	25	0.49	1.41	0.096
AOC	118.80	75	0.44	0.78	0.099
CS - within groups	414.72	240	0.35		
TC	18.00	25	0.48	0.86	0.662
ATC	30.80	75	0.44	0.78	0.911
OTC	146.25	125	10.76	19.02	0.001*
AOTC	290.25	375	1.23	2.17	0.001*
TCS - within groups	950.40	1200	0.56		

[a] Age, [b] Order, [c] Target, [d] Condition

* $p < .001$, ** $p < .05$

Table 5

Summary Table of F-Ratios for Predictions in the Indirect Aiming Task Using Metric Data

Part of Model	Sum of Squares	Degrees Freedom	Mean Squares	F Ratio	Probability
A[a]	1271.60	3	423.87	1.69	0.100
O[b]	259.15	5	51.83	0.21	0.959
AO	2030.70	15	135.38	0.54	0.905
S - within groups	12067.89	48	251.41		
T[c]	1268.16	5	253.63	9.14	0.001*
AT	1039.85	15	69.32	2.50	0.002*
OT	909.17	25	36.37	1.31	0.153
AOT	2003.54	75	26.71	0.96	0.567
TS - within groups	6659.12	240	27.75		
C[d]	104.03	5	20.81	0.85	0.519
AC	587.93	15	39.20	1.59	0.076
OC	2137.42	25	85.50	3.47	0.001*
AOC	1519.95	75	20.27	0.82	0.838
CS - within groups	5907.77	240	24.62		
TC	853.95	25	34.16	1.13	0.302
ATC	1663.83	75	22.18	0.73	0.957
OTC	34633.67	125	277.07	9.15	0.001*
AOTC	19136.99	325	51.03	1.69	0.001*
TCS - within groups	36353.82	1200	30.30		

[a]Age, [b]Order, [c]Target, [d]Condition

* $p < .001$

recorded as metric data. Subjects were asked to draw in chalk the path they predicted the ball would travel. The distance between this line and the actual path of the ball (previously determined) was measured in inches.

Task Factors

As reflected in Table 4, significant main effects for age, $\underline{F}$ (3,48) = 4.79, $\underline{p}$ < .005, and target, $\underline{F}$ (5,240) = 6.35, $\underline{p}$ < .001, were obtained for the category data as well as a significant age x target interaction, $\underline{F}$ (15,240) = 1.91, $\underline{p}$ < .023, order x target x condition interaction, $\underline{F}$ (125,1200) = 19.02, $\underline{p}$ < .001, and age x order x target x condition interaction, $\underline{F}$ (375,1200) = 2.18, $\underline{p}$ < .001. Somewhat similar results were found for the metric data (refer to Table 5) although, no significant main effects were found for age, only for target, $\underline{F}$ (5,240) = 9.14, $\underline{p}$ < .001. As with the category data, significant interactions between age and target, $\underline{F}$ (15,240) = 2.50, $\underline{p}$ < .002, order x target x condition, $\underline{F}$ (125,1200) = 9.15, $\underline{p}$ < .001, and age x order x target x condition, $\underline{F}$ (375,1200) = 1.69, $\underline{p}$ < .001 were also present. An additional interaction between order and condition, $\underline{F}$ (25,240) = 3.47, $\underline{p}$ < .001, was found which was not present with the category data. Again, using the Greenhouse Gieser procedure with both types of data produced similar results. The following paragraphs apply to analysis of both category and metric data.

Before examining the higher order interactions, a preliminary analysis of the significant main effects and lower order interactions will be made. As in the first experiment, age effects were present (although they were significant using only category data). This time however, 7 year olds performed more poorly than any other group (although significantly more poorly than only the 9 and 11 year olds, i.e., not the 5 year olds) (refer to Table 6). Even so, 5 and 7 year old performances were more similar (M = 0.432 and 0.636, respectively with category data, 2.926 and 4.036, respectively with metric data) as were 9 and 11 year old performances (M = 0.287 and 0.227, respectively with category data and 2.621 and 2.127, respectively with metric data). Based on performance in experiment 1 in which all age groups were able to successfully manipulate the chute, it may be suggested response loaded factors were not the major determinants responsible for deficits in performance particularly in the younger age groups. Poor 7 year old performance may have been reflective of an attempt to shift to a more mature strategy by this group in their predictions. It was observed that some five year olds tended to draw out the path of the ball with their finger or arm and then select their category of choice. Nine and 11 year olds were observed to trace an imaginary line

Table 6

Mean Error Score for Each Age Group Collapsed Over Targets Using Category and Metric Data

Age	Category Data (in units)	Metric Data (in in.)
5	0.432	2.926
7	0.636	4.036
9	0.287	2.621
11	0.227	2.127

with their eyes. It may have been that 7 year olds were in a stage of transition in which some were attempting to apply this latter strategy but did so somewhat inefficiently. While 7 year olds may have been changing their strategy, it could not be reflected in the metric data. To obtain these measures, subjects were asked to draw the path of the ball with a piece of chalk. Again 5 year olds as a group out performed the 7 year olds. A second likely explanation, at least for the difference between 5 and 7 year olds, is that the 5 year olds were applying a hit strategy. In fact, this is the case in that 5 year olds predicted a disproportionately large percentage of balls would hit the target, 60.49% compared to the 33.33% predetermined to hit. Seven year olds predicted 46.14% would hit the target as illustrated in Table 7. Further, seven year olds predicted 58.15% of the balls would roll below the target (as opposed to the actual 16.67%). It may be suggested that this strategy shows a lack of differentiation by 5 year olds with regard to movements of the chute. Thus, while the 7 year olds may have correctly known the ball would not hit the target more times than the 5 year olds, the size of the error score increased due to the preponderance of below target predictions that they made. It is interesting to note that nine and eleven year olds predicted 33.02% and 35.80% hits respectively.

Table 7

Frequency and Percentage of Predictions Made for each Condition Using Category Data

	Expected		Observed							
			5		7		9		11	
Condition	N	%	N	%	N	%	N	%	N	%
AN	108	16.67	16	2.47	24	3.70	103	15.90	90	13.89
AF	108	16.67	20	3.09	13	2.01	56	8.64	67	10.34
H	216	33.33	392	60.49	299	46.14	214	33.02	232	35.80
BN	108	16.67	85	13.12	164	25.31	154	23.77	147	22.69
BF	108	16.67	122	18.83	148	22.84	121	18.67	112	17.28
Other			13	2.01						
Total	648	100	648	100	648	100	648	100	648	100

AN = Above Near, AF = Above Far, H = Hit, BN = Below Near, BF = Below Far

All four age groups tended to predict the path of the ball below its actual path (reflected by a negative constant error score).

While the targets closest to the side wall (refer to figure 9 for placement of the targets) tended to be more difficult (particularly target 5), the younger groups tended not to differentiate as much between the degree of difficulty of the various targets. That is, the younger age groups (5 and 7 year olds combined) were not significantly better on the easier tasks (targets 1, 3 and 4 combined) than on the difficult tasks (targets 5, 6 and 1 combined). (It should be noted that these groupings were done post hoc based on the results of the Scheffe test. That is, there were no predetermined 'easy' and 'difficult' targets, such a differentiation is based entirely upon performance results.) The older age groups (9 and 11 year olds combined), while performing better on both tasks than the younger group,were differentially affected by the placement of the targets (see figure 10).

In manipulating the context of the targets for subjects, (i.e., the problem type, or condition, and its order of presentation for each subject) an order by target by condition interaction occurred. Significant effects within the interaction appear quite disparate; however, based on the results of Scheffe tests, the

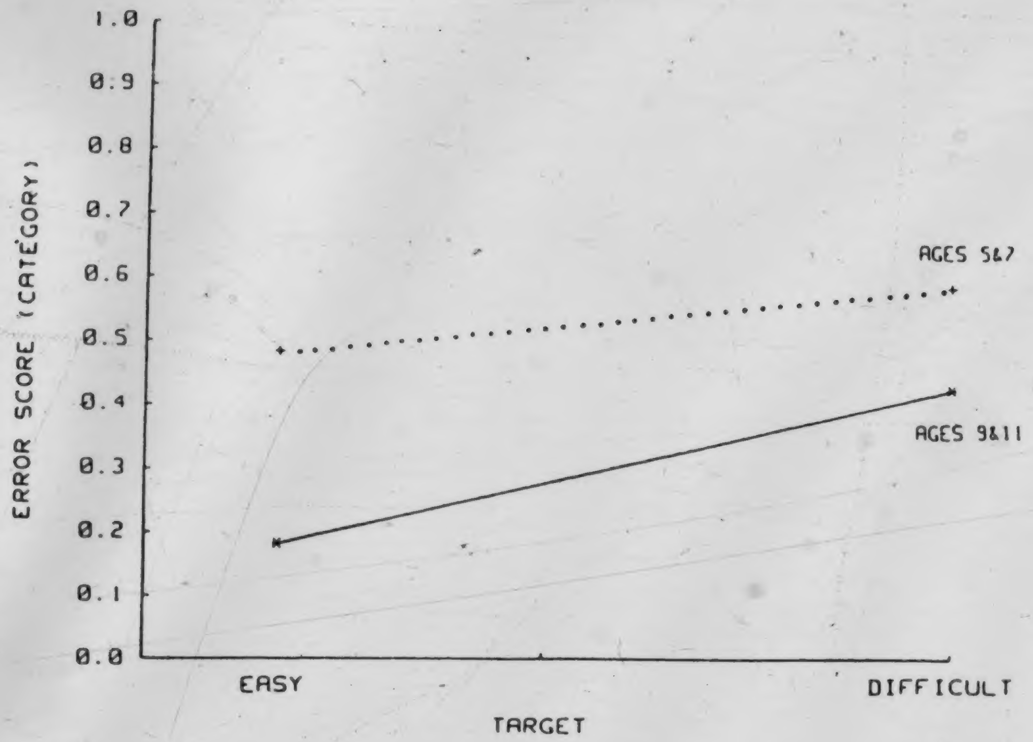

Figure 10. Mean error scores on targets (grouped by difficulty) as a function of age (grouped by old and young)

number of variables within each factor was collapsed resulting in a new 3 x 2 x 3 (Order x Target x Condition) analysis of variance. In the original analysis, no main effect for order was present although three groupings were apparent. In two of these, the sequence, or order, of the conditions reflected a certain similarity in proximal items. Different levels of the condition categories (excluding catch trials) appeared sequentially, e.g., order 2: AF,AN,BN,C2,BF,C1; order 5: C1,BF,C2,BN,AN,AF. In the third main grouping, the sequence of conditions appeared to be more random, e.g., order 3: BN,AF,BF,AN,C1,C2; order 6: C1,C2,AN,BF,AF,BN. Targets were again divided on a post hoc basis into 2 groups - easy and difficult; and, conditions were grouped into like categories in terms of their placement on the board relative to the target, e.g., A (AN + AF), B (BN + BF); C (C1 + C2). The random order of presentation would appear to differentially affect both the easy and difficult targets on the A (above) and B (below) conditions (see Figure 11). This effect was particularily dramatic between the two age categories - young (5 + 7 years) and old (9 + 11 years) resulting in an age by order by target by condition interaction (refer to Figure 12).

The results of this analysis indicate task factors had a differential effect on subjects' performance at

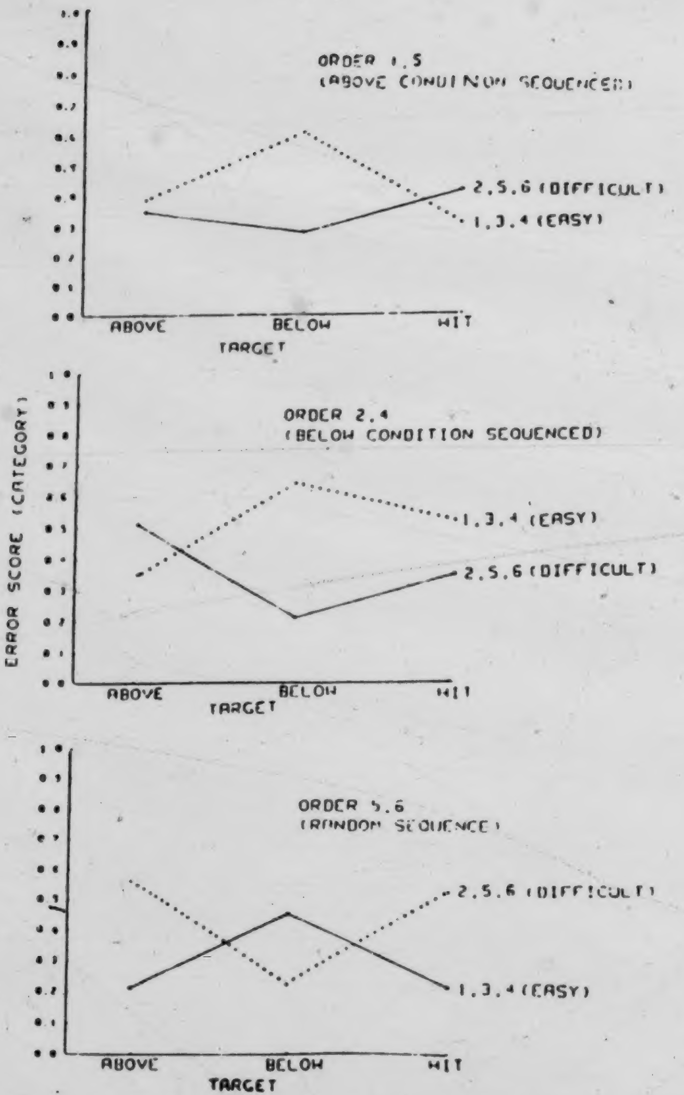

Figure 11. Mean error score for condition category (i.e., above, below, hit) as a function of target (grouped by difficulty) and order of presentation (grouped according to sequence).

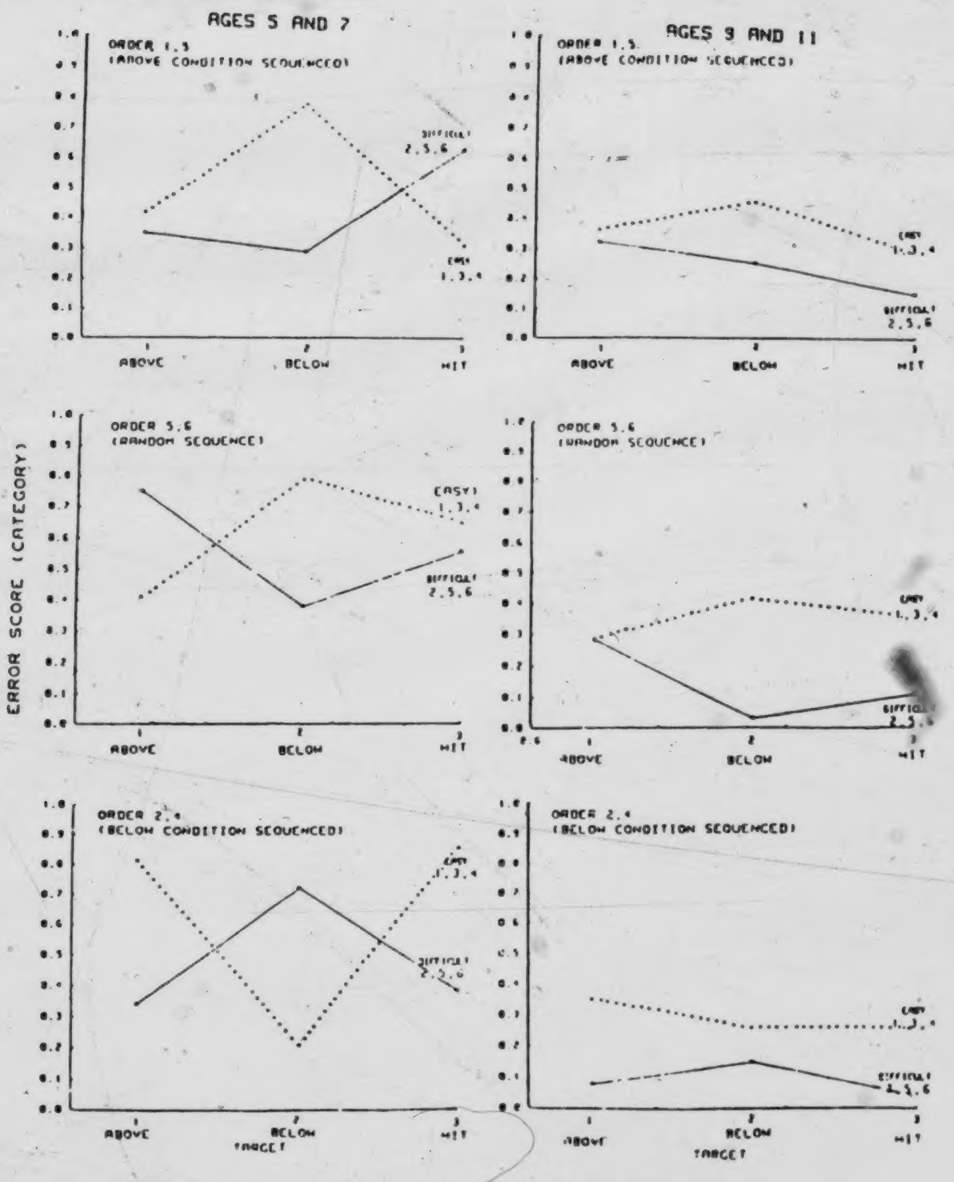

Figure 12. Mean error score for condition category (i.e., above, below, hit) as a function of target (grouped by difficulty), order of presentation (grouped by sequence) and age (grouped by young and old).

certain age levels. While performance across all four age groups was detrimentally affected by the increased complexity (or difficulty) of the task, the younger groups were affected much more readily than the older ones. The task would thus, seem to be a sensitive one capable of discrimminating across ages the (declarative and procedural) knowledge base on which subjects base their predictions.

Knowledge-Performance Categories of Subjects

In order to present a more visual representation of the subjects' knowledge base as reflected by the accuracy of their predictions, as in experiment one, three knowledge-performance categories were developed based on the frequency of error scores across all age groups. As in experiment 1, knowledge categories were developed based on the size of the error scores (i.e., subjects' accuracy). Collapsing over targets, subjects' error scores were converted to root mean square error and subjects were then classified as being low knowledge, medium knowledge or, high knowledge. (Actual boundary figures for the knowledge categories are found in Appendix B.)

Experiment 2 represents categorical predictions of the path of the ball without feedback. As in the previous experiment, clear developmental trends are apparent in both the metric and category data (refer to Table 8). Five and seven year olds responded more as a group moving from low to medium knowledge categories, as did the 9 and 11 year olds moving from the medium to high knowledge category. Virtually no younger subjects (i.e., only 1 seven year old) were categorized as high knowledge. The reverse is true of the older age groups with only two from each of the 9 and 11 year old groups categorized as low knowledge. Again, the above secondary analysis supports the fact that the task is sensitive to knowledge-performance differences across age groups.

Table 8

Distribution of Subjects by Age Over Knowledge Categories Using Category and Metric Data

	Age (in yrs.)							
	5	7	9	11	5	7	9	11
Knowledge Category	Metric				Category			
low	10	12	1	0	12	8	2	2
medium	8	5	7	6	6	9	3	7
high	0	1	10	12	0	1	13	9

Experiment 3

In the previous experiment subjects used their extant declarative and procedural knowledge to make predictions on the task under various conditions. In experiment 3, subjects once again had to use this task-specific declarative and procedural knowledge, however, this time they received feedback on the efficacy of their actions. The third experiment was designed to measure subjects' procedural knowledge (and necessarily the closely tied declarative knowledge on which the procedures are largely based) in the execution of an indirect aiming task.

Sample

Those subjects used in the previous two experiments were also used in experiment 3.

The Task

The task was the same as the indirect aiming task of experiment 2.

Apparatus

The same apparatus of experiment 2 was used in experiment 3.

Procedure

In this experiment, subjects were required to determine the correct lateral position of the chute which would result in the ball hitting the target. The pattern of adjustments of the chute (i.e., the error correction pattern) was used to reflect the degree of procedural knowledge in relation to the declarative knowledge base that was presumed to have been used in the previous experiment. Thus, for subjects exhibiting a strong declarative knowledge-base in experiment 2, adjustments in the wrong direction would suggest difficulties in the procedural knowledge-base underlying the successful execution of the aiming task. Again, the basic assumption is that the performance error score of the subjects is a direct reflection of their underlying procedural knowledge-base on this task.

The chute was set such that the ball would miss the target. This was shown to each subject by rolling the ball down the chute. The starting position of the chute was marked on the board with a piece of coloured chalk. Subjects were required to adjust the lateral position of the chute to make it hit the target. A maximum of 10 trials was allowed. As in experiment 1, if subjects hit the target in less than 10 trials, each trial subsequent to the hit was recorded as an error of 0. A strip of tape was placed vertically down the board through the target position. Once the chute was positioned such that a subject felt the ball would hit the target, the principle investigator released the pin holding the ball in place. As the ball rolled down the chute and rebounded off the wall across the board, the place at which it crossed the tape was marked with a piece of chalk by the second investigator. The distance between this point and the target was calculated. A second measure was taken by noting the position of the chute on the tailor's tape at the front of the board. The path of the ball was thus verified at the end of the experiment by repositioning the chute at that point and allowing the ball to be released again. If there was a discrepancy, this second measurement would have been used; however, this was never necessary.

The entire procedure was repeated for six different targets (targets were varied by changing the angle of the chute and the position of the targets on the board). Targets were the same as those used in experiment 2 (illustrated in Figure 9). Presentation order was digram balanced; however, subjects again remained in the same presentation as in the previous experiments. Thus, the experimental design was a 4 x 6 x 6 x 10 (Age x Order x Target x Trial) factorial design with repeated measures on the last two factors.

Performance on the Indirect Aiming Task

The effects of task related factors will be presented first through the results of an analysis of variance. Analysis of knowledge related factors will then be presented as well as the interaction of knowledge factors between experiments 2 and 3.

Task Factors .

The dependent variable in experiment 3 was subjects' error scores measured (in inches) as the distance between the actual path of the ball and the target. Group performance differences were analyzed using a 4 x 6 x 6 x 10 (Age x Target x Order x Trial) analysis of variance with repeated measures on the last two variables. As shown in Table 9, significant main effects for age, $\underline{F}$ (3,48) = 2.89, $\underline{p} < .047$, and trial, $\underline{F}$ (9,432) = 6.44, $\underline{p} < .001$, were obtained, as well as a significant age x trial interaction, $\underline{F}$ (27,432) = 1.67, $\underline{p} < .021$, order x target interaction, $\underline{F}$ (25,240) = 6.06, $\underline{p} < .001$, order x target x trial $\underline{F}$ (225,2160) = 2.34 $\underline{p} < .001$ and age x order x target x trial interaction, F (675, 2160) = 1.24, $p < .001$.

As in experiment 2, before examining the higher order interactions, a preliminary analysis of the significant main effects and lower order interactons will be made. Error scores decreased as age increased with a

Table 9

Summary Table of F-Ratios for the Indirect Aiming Task

Part of Model	Sum of Squares	Degrees Freedom	Mean Squares	F Ratio	Probability
A[a]	806.46	3	268.82	2.89	0.047**
O[b]	240.85	5	92.94	1.59	0.183
AO	1906.65	15	127.11	1.37	0.209
S - within groups	4461.16	48	92.94		
T[c]	165.45	5	47.66	0.95	0.447
AT	787.65	15	52.51	1.05	0.405
OT	7577.50	25	303.10	6.06	0.001*
AOT	3669.75	75	48.93	0.98	0.532
TS - within groups	11995.20	240	49.98		
TR[d]	636.84	9	70.76	6.44	0.001*
ATr	495.18	27	18.34	1.67	0.021**
OTr	655.66	45	14.57	1.33	0.086
AOTr	1283.84	136	9.44	0.86	0.850
TrS - within groups	4747.68	432	10.99		
TTr	397.80	45	8.84	0.95	0.577
ATTr	1381.05	135	10.23	1.09	0.227
OTTr	546.25	225	21.85	2.34	0.001*
AOTTr	7836.75	625	11.61	1.24	0.001*
TTrS - within groups	20217.60	2160	9.36		

[a]Age, [b]Order, [c]Target, [d]Trial

* *p* < .001, ** *p* < .05

significant difference in performance between the 5 year olds and the 11 year olds. The increased degree of difficulty of this task as opposed to that of experiment 1 is reflected not only in the size of the error score for all age groups, but the increased number of orienting trials needed by the subjects. Clearly, expecting the subjects to handle different target positions and flexibly adjust their predictions in an indirect aiming task as opposed to the direct one used in experiment 1, resulted in increased task demands for the subjects. As illustrated by Table 10, in this task the first four trials seemed to be used as orienting trials (as opposed to the first two in Experiment 1). As subjects had no information on which to base their first trial, error scores were particularly large on this trial across all age groups. Post hoc tests showed that trial 1 (M = 1.294) was significantly more errorful than trials 10,9,7,6 and 5 (M = 0.031, 0.120, 0.190, 0.294, 0.401, respectively). These results suggest that after the initial orienting trials, subjects were then able to use information of the effect of each trial as feedback for subsequent trials. Further, for no group did the error score reach zero as it did in experiment 1. Again, it may be suggested that this is indicative of the increased difficulty of having to bank the ball off the side wall to hit the target. Under these circumstances, rather than being able to make direct corrections with the chute, subjects had to predict the appropriate vertical contact point on the side wall and translate that into a lateral movement of the chute. While exactly the same rules are used, the ball does not travel directly towards the target thus creating an extra dimension of complexity. As seen in table 10, five year olds were particularly affected by the increased difficulty of the task on the initial orienting trial.

The order by target interaction, while somewhat disparate, seems to be a function of the placement of the target and the consistency with which targets in close vicinity are ordered. That is, targets in close vicinity to one another presented consecutively were easier than widely separated targets presented consecutively. The position of the targets can be seen in Figure 9. As reflected by the mean error scores in Table 11, under order 2 (in which targets were presented in the following order: 2,1,3,6,4,5), targets 2, 4 and, 5 were performed significantly more poorly than targets 1, 2 and, 6. Similarly, under order 3 (in which targets were presented in the following order: 3,2,4,1,5,6), targets 3, 4 and, 6 were performed significantly better than targets 5 and 2. Under presentation order 4 (targets were presented in the following order: 4,3,5,2,6,1) target 1 was performed significantly more poorly than target 3. Finally, under presentation order 6 (in which targets were presented in

Table 10

Mean Error Score by Trial as a Function of Age

	Age (in yrs)			
Trial	5	7	9	11
1	3.523*	1.426	0.357	0.622
2	1.606*	1.021	1.052	0.878
3	0.854	0.250	0.193	0.999
4	0.672	0.260	0.231	0.275
5	0.962	0.252	0.469	0.099
6	1.676	0.071	0.377	0.359
7	1.056	0.130	0.298	0.193
8	1.651	0.234	0.244	0.035
9	1.009	0.021	0.148	0.369
10	0.591	0.073	0.129	0.339

* $p < .001$

Table 11

Mean Error Score (in inches) on Targets as a Function of Presentation Order

	Target					
Order	1	2	3	4	5	6
1	0.882	0.195	0.752	0.875	0.109	1.926
2	0.785	2.948	0.318	3.157	3.944	1.648
3	0.152	1.245^{a}	3.177^{b}	1.282^{b}	2.897^{a}	1.164^{b}
4	2.356^{a}	0.889	1.360^{b}	0.061	1.422	0.194
5	0.017	2.434	1.360	0.061	1.422	0.194
6	1.973^{a}	0.662	0.821	1.913^{a}	2.120^{b}	0.064

Note : Within each order, means with different subscripts are significantly different at $p < .001$

the following order: 6,5,1,4,2,3) targets 4 and 1 were performed significantly better than target 5. Thus, this pattern of results supports the contention that targets in close proximity presented consecutively were easier for the subjects than those spaced further apart.

Targets 2 and 3 presented in order 5 (5,4,6,3,1,2) and target 5 presented in order 4 (4,3,5,2,6,1) were significantly more errorful across all age groups on trials 1 and 2 than the later trials (i.e., 6,7,10). Again a dramatic shift in the position of the target may have made the initial orienting trials more difficult. This was particularly true for the five year olds (reflected in the age by order by target by trial interaction). Five year old's error scores were even more inflated on orders of presentation in which the targets not in close vicinity to one another were presented consecutively, that is, when targets were fairly disparate. This was particularly true for two presentation orders: order 2 in which targets were presented in the following order, 2,1,3,6,4,5; and, order 4 in which targets were presented in the following order, 4,3,5,2,6,1.

Knowledge-Performance Categories of Subjects

As in experiment 1, knowledge categories were developed based on the size of subjects' error scores.

Subjects' scores on trials 1,2,3,6 and, 10 were converted to root mean square error. Based on the frequency and distribution of the scores, three knowledge categories were established at the 33.3 and 66.7 percentile points. Actual boundary figures for the knowledge categories are found in Appendix B. Subjects were then assigned to one of the categories based on their error scores (converted to mean square error). Distribution of subjects over knowledge categories is found in table 12.

As in the previous experiment, 5 year olds were clumped in the low knowledge category and 11 year olds in the high. Seven year olds' performance was similar to that of the 5 year olds and 9 year olds similar to the 11 year olds. It may be more accurate to suggest 7 year olds were making the transition from low to medium knowledge and the 9 year olds that from medium to high knowledge. Looking at the second trial, i.e., the first opportunity subjects ~~have of~~ actually applying their knowledge to reduce the performance error, these developmental trends are particularly clear. It may be suggested that this trial represents the status of the procedural knowledge subjects brought to the task. Very little movement was made by 5 year olds towards higher knowledge categories over the ten trials. Excluding trial 1, which may be considered an initial 'blind' trial, the percentage of low knowledge subjects remained

Table 12

Distribution of Subjects by Age and Trial Over Knowledge Categories

		Age			
Trial	Category	5	7	9	11
1	L	10	6	3	5
	M	6	7	9	3
	H	2	5	6	10
2	L	14	5	2	3
	M	3	9	8	4
	H	0	4	8	11
3	L	13	7	1	4
	M	2	5	9	7
	H	3	6	8	7
6	L	14	7	2	2
	M	4	7	7	5
	H	0	4	9	11
10	L	14	8	2	1
	M	2	4	3	6
	H	2	6	13	11

L = Low, M = Medium, H = High

constant at 78%. Several of the subjects moving in and out of the medium and high knowledge categories were those using the random, almost flamboyant movements of the chute back and forth across the board. To suggest that they had a good knowledge of the rules (i.e., high or medium knowledge) is somewhat misleading (although the presence of variability corrects, to some extent, this impression). A more likely interpretation is that they inadvertently moved into the various knowledge categories.

Variability is particularly evident in the categorization of 7 year olds. While the distribution of subjects across all three categories is much more even, subjects fluctuate back and forth between the low and medium knowledge groups over trials. Those subjects in the high group remained fairly stable over the trials. A greater change in the distribution of subjects between categories and their movement patterns across trials seems to take place between the ages of 7 and 9. While some shifting between categories is evident by the 9 year olds, the trend is always toward the higher knowledge category. Between the first and tenth trials, approximately 7, or 39% of subjects, moved to the high knowledge category mainly from the medium knowledge category (after the first orienting trial, the number of subjects in the low group virtually remained the same).

The percentage of subjects from the 11 year old group reaching the high knowledge category was somewhat less than the proportion of 9 year olds (61% and 72%, respectively). A progressive, albeit limited depletion of subjects from the low knowledge category, towards a higher knowledge category (mainly to the medium knowledge group) is evident across trials. Apart from this learning, little movement between groups was evident (other than trial 3). This is in particular contrast to experiment 1 in which subjects, across all age groups, moved fairly rapidly to the high knowledge category. As with experiment 2, this indirect aiming task is sufficiently difficult to provide a clear developmental differentiation of subjects' performance.

The preceding results, while based on the process of categorizing individual subjects into knowledge groups, allows only a group analysis. That is, only the number of subjects in each category can be traced, not the movement of the individual subjects over trials. When individual subjects are followed (see Tables 21 and 22), it becomes clear for example, that while the number of 9 year olds in the high knowledge group across trials may be greater than that for the 11 year olds, the same individuals do not always make up this number. Thus, there is greater intra-individual variability for 9 year olds than the 11 year olds. Eleven year old performance is more stable than that of the nine year olds. A similar subject by subject analysis across trials shows individual 5 year old performances to be very stable in the low knowledge group and individual 7 year old performances to be quite variable. Results of the subject by subject analysis will be discussed later on in the next section as the effect of knowledge category in experiment 2 on that in experiment 3 is analyzed.

Cross Tabulation of Knowledge Categories

A cross tabulation of knowledge categories determined in Experiment 2 was done with those of each trial (i.e., trials 1,2,3,6 and, 10) in Experiment 3. Such a procedure highlights the relationship between subjects' classifcation in experiment 2 with that in experiment 3. Assuming subjects' declarative and procedural knowledge underlying the prediction task of experiment 2, is crucial to, or even a prerequisite of successful performance in experiment 3, distinct patterns of performance should be evident depending on subjects' categories of knowledge. A series of three analyses will be presented each providing a slightly different insight into the relationship between subjects' classifications on experiment 2 with that on experiment 3. The first two involve group analysis techniques and while highlighting certain developmental trends, they do not adequately represent the actual pattern of performance based on the knowledge-performance categories of subjects and in fact at times misrepresent the actual pattern. The third analysis is thus a subject by subject review of performance reults.

Tables 13 through 16 show the movement of subjects across knowledge categories between the two experiments in terms of both the frequency of subjects in each cell and the corresponding percentage of subjects (tables 13 and 14 refer to category data and Tables 15 and 16 refer to the metric data of experiment 2). In these tables, age groups have been combined. A breakdown by age can be found in Appendix C. As is evident from the tables in the appendix, there was very little movement in the two extreme age groups. Based on the category predictions, 50 percent of the 5 year olds remained in the low knowledge group in both experiments while 39% of the 11 year olds remained in the high knowledge category (refer to Appendix C). Both the 7 and 9 year olds showed much greater variability but even here, the 7 year olds tended to fluctuate between the lower and medium knowledge categories while the 9 year olds tended to fluctuate between the medium and high categories. That is, by the tenth trial, 50% of all nine year olds classified as high on experiment 2 had moved to the high group on experiment 3.

Table 13

Cross Tabulation of Knowledge Categories of Experiment 2 (Prediction Task) with Experiment 3 (Hitting Task) Using Category Data: Frequency of Subjects per Category by Trial

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
low	24	9	10	5	13	8	3	14	3	7	13	7	4	14	4	6
medium	25	11	9	5	9	11	5	10	8	7	10	8	7	10	6	9
high	23	4	6	13	2	6	15	1	12	10	2	8	13	1	5	17
Total	72	24	25	23	24	25	23	25	23	24	25	23	24	25	15	32

Table 14

Cross Tabulation of Knowledge Categories of Experiment 2 (Prediction Task) with Experiment 3 (Hitting Task) Using Category Data: Percentage of Subjects per Category by Trial

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	33	38	40	22	54	32	13	56	13	29	52	30	17	56	27	19
Medium	35	46	36	22	38	44	22	40	35	29	40	35	29	40	40	28
High	33	17	24	57	8	24	65	4	52	42	8	35	54	4	33	53
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 15

Cross Tabulation of Knowledge Categories of Experiment 2 (Prediction Task) with Experiment 3 (Hitting Task) Using Metric Data: Frequency of Subjects per Category by Trial

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
low	23	9	9	5	11	9	3	14	3	6	12	7	4	11	4	8
medium	26	11	10	5	11	10	6	10	7	9	12	8	6	13	6	7
high	23	4	6	13	2	6	15	1	13	9	1	8	14	1	5	17
Total	72	24	25	23	24	25	23	25	23	24	25	23	24	25	15	32

Table 16

Cross Tabulation of Knowledge Categories of Experiment 2 (Prediction Task) with Experiment 3 (Hitting Task) Using Metric Data: Percentage of Subjects per Category by Trial

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	32	38	36	22	46	36	13	56	13	25	48	30	17	44	27	25
Medium	36	46	40	22	46	40	26	40	30	38	48	35	25	52	40	22
High	32	17	24	57	8	24	65	4	57	38	4	35	58	4	33	53
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Measures of Association

Measures of association typically indicate the advantage of prior information of one factor on predicting another. Several such measures will be identified here in terms of the relationship they portray between the extent of the declarative and procedural knowledge that is assumed to underlie performance in experiment 2 to anticipate successful performance in experiment 3.

The way in which the distribution of scores is handled in a cross tabulation, particularly those that are tied, accounts for the major distinctions between the most commonly used measures of ordinal association. Goodman and Kruskal's gamma does not consider any score which may be tied (Reynolds, 1978). That is, it gives the difference in probabilities of concordance and discordance among untied pairs. Since tied pairs are omitted from the denominator the absolute value of γ increases and may over shoot a particular relationship. As noted by Reynolds (1978), the value of γ reaches its maximum under conditions of very weak perfect association (p.68) and may be useful for hypotheses of very weak perfect correlations but it provides little information of the underlying relationships of variables.

Kendall's tau b (τ_b) does consider ties on each variable; however, it too has several draw backs. It considers all errors as being of an equal degree of severity. As with other measures, it does not reach its maximum for non-square matrices. Further, in both of these measures, the distribution of the independant variable will affect its value. That is, observations that are highly skewed or are concentrated in a particular category will easily result in underestimation of the true measure of the association.

As expected in light of their general naivete (Brown and De Loache, 1978), and as illustrated earlier in Tables 13 to 16, the younger age groups (5 and 7 years) are largely grouped in the low knowledge categories on both experiment 2 and 3. Conversely, the older age groups (9 and 11 years) are largely grouped in the high knowledge category producing highly skewed marginal distributions. Thus, while gamma and tau b are reported here in Tables 17 and 18, their application is somewhat limited. Notwithstanding these limitations, a general trend of association is apparent. As age increases, the association seems to get stronger. When all age groups are combined, a similar strengthening of association is apparent over trials. Broken down by age however, the pattern of association seems quite disparate.

Using Hildebrand, Laing and Rosenthal's (1977)

Table 17

Summary Table of Measures of Association Between Knowledge Classification in Experiment 2 (Prediction Task) and Experiment 3 (Hitting Task) Using Category Data

Age	Dependent Variable	Independent Variable	Gamma (γ)*	Tau b (τ_b)	Delta P (∇P)	
					∇P_1^b	∇P_2^a
All	Exp.2	Exp.3 Trial 1	0.351 (0.438)	0.242		
		2	0.619 (0.774)	0.441		
		3	0.427 (0.534)	0.301		
		6	0.532 (0.665)	0.371		
		10	0.600 (0.750)	0.419		
5	Exp.2	Exp.3 Trial 1	0.000 (0.000)	0.000	-0.100	0.100
		2	-0.250 (-0.313)	0.095	-0.109	0.071
		3	0.294 (0.368)	0.140	0.226	0.077
		6	-1.000 (-1.000)	-0.378	0.435	0.286
		10	-0.154 (-0.192)	-0.061	0.455	0.071
7	Exp.2	Exp.3 Trial 1	0.188 (0.234)	0.123	0.172	0.153
		2	0.483 (0.684)	0.295	0.237	0.514
		3	0.226 (0.282)	0.143	0.056	0.438
		6	0.118 (0.147)	0.083	-0.064	0.449
		10	-0.194 (-0.242)	0.125	-0.166	0.167
9	Exp.2	Exp.3 Trial 1	-0.070 (-0.087)	-0.036	-0.071	0.085
		2	0.200 (0.250)	0.109	0.135	0.159
		3	-0.500 (-0.625)	-0.250	0.528	0.151
		6	-0.300 (-0.375)	-0.146	0.115	0.164
		10	-0.032 (-0.040)	-0.014	0.154	0.154
11	Exp.2	Exp.3 Trial 1	0.477 (0.596)	0.326	0.192	0.331
		2	0.563 (0.703)	0.392	0.272	0.345
		3	0.412 (0.515)	0.280	0.092	0.387
		6	0.439 (0.548)	0.275	0.383	0.045
		10	0.714 (0.893)	0.451	0.492	0.629

*Gamma corrected for size of matrix

Based on prediction 1, Based on prediction 2

Table 18

Summary Table of Measures of Association Between Knowledge Classification in Experiment 2 (Prediction Task)and Experiment 3 (Hitting Task) Using Metric Data

Age	Dependent Variable	Independent Variable		Gamma	(γ)*	Tau b (τ_b)	Delta P (∇P)	
							∇P^a_1	∇P^b_2
All	Exp.2	Exp.3 Trial	1	0.360	(0.450)	0.247		
			2	0.568	(0.710)	0.402		
			3	0.423	(0.534)	0.300		
			6	0.558	(0.697)	0.393		
			10	0.482	(0.602)	0.334		
5	Exp.2	Exp.3 Trial	1	-0.348	(-0.435)	-0.187	-0.100	0.100
			2	-1.000	(-1.000)	0.478	-0.109	0.071
			3	0.143	(-0.179)	0.066	0.226	0.077
			6	-1.000	(-1.000)	-0.478	0.435	0.286
			10	0.250	(0.313)	0.229	0.455	0.071
7	Exp.2	Exp.3 Trial	1	0.346	(0.432)	0.209	0.172	0.153
			2	0.692	(0.865)	0.408	0.237	0.514
			3	0.700	(0.875)	0.463	0.056	0.438
			6	0.357	(0.446)	0.222	-0.064	0.449
			10	-0.170	(-0.212)	-0.101	-0.166	0.167
9	Exp.2	Exp.3 Trial	1	-0.259	(-0.324)	-0.151	-0.071	0.085
			2	0.192	(0.240)	0.109	0.135	0.159
			3	-0.857	(-1.000)	-0.546	0.528	0.151
			6	-0.346	(-0.433)	-0.198	0.115	0.164
			10	-0.135	(-0.169)	-0.064	0.154	0.154
11	Exp.2	Exp.3 Trial	1	0.746	(0.932)	0.496	0.192	0.331
			2	0.825	(1.000)	0.587	0.272	0.345
			3	0.800	(1.000)	0.552	0.092	0.387
			6	0.750	(0.938)	0.455	0.383	0.045
			10	0.733	(0.917)	0.427	0.492	0.629

***Gamma corrected for size of matrix**

Based on prediction 1, Based on prediction 2

prediction logic technique for evaluation of the degree of association between two variables, it is possible to avoid some of the aforementioned problems and gain a somewhat more accurate measure of the relationship between 2 variables. The technique has a proportionate reduction in error (PRE) interpretation. PRE measures reflect the reduction in error rate in making predictions based on some proposition versus making a prediction with no information. The basic prediction underlying this investigation states that knowledge in experiment 2 (the prediction task) will assist subjects in hitting the target in experiment 3. That is, the declarative and procedural knowledge base underlying the predictions made in experiment 2 will be reflected in the procedural knowledge used in experiment 3. In this case, knowledge categories of experiment 2 ~~are the~~ independent variable (X) and knowledge categories of experiment 3, the dependent variable (Y). More specifically then, the proposition under consideration states: $P = X \rightsquigarrow Y$. That is, P: "Predict y_1 if x_1, y_2 if x_2, y_3 if x_3". ($\rightsquigarrow$ reads "predicts" or "tends to be sufficient for" (Hildebrand, Laing and Rosenthal, 1977)). Such a proposition also identifies a set of error events shown by the hatched cells in figure 11, that falsify the prediction.

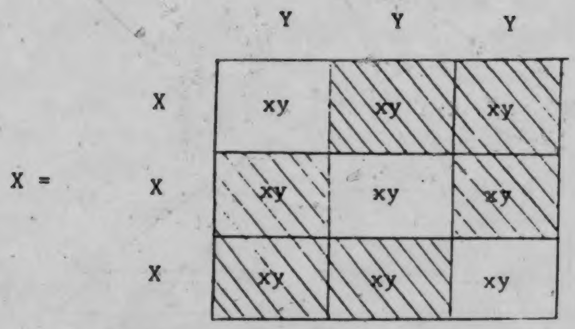

Figure 13 . Hatched squares representing the error cells falsifying the prediction $P = X \rightsquigarrow Y$.

If the prediction is perfectly achieved (in the most strict sense (Reynolds, 1978)), all data points will fall on the main diagonal; however, this was not the case in this investigation (and generally, is not the case in most studies) and error scores must be considered as part of the total story. In the context of a particular prediction, some errors may be considered a more serious violation of the prediction than others (Hildebrand, Laing and Rosenthal, 1977). A weighting system (W) can be assigned to reflect a particular sequence of errors. The weights could range from 0 to 1 with $W = 0$ representing a success. The most serious errors would then be represented by $W = 1$ and values in between would denote measures or degrees of the seriousness of the error events. The actual weighting system can be determined using the following formula:

$$W = \frac{v^2}{ij}$$

where W represents the weight for a particular error cell; v is the number of units of distance from the predicted set, in this case the diagonal (this reflects the order of severity of errors), and i and j reflect the number of rows and columns, respectively, in the matrix. The maximum error weight assigned is 1.0 and, as mentioned previously, the minimum is 0 (perfect prediction).

The basic prediction model (or measure of association) uses the following form:

$$\nabla P = \frac{\Sigma_i \Sigma_j \; N_i P_j - NP_{ij}}{\Sigma_i \Sigma_j \; NP_i P_j} \qquad 1$$

$$= 1 - \frac{\Sigma_i \Sigma_j \; P_{ij}}{\Sigma_i \Sigma_j \; P_i P_j} \qquad 2$$

(cells of an R x C matrix contain probabilities Pij).

The weighted error reduction measure then becomes:

$$W\nabla P = 1 - \frac{W\Sigma_i \Sigma_j \; P_{ij}}{W\Sigma_i \Sigma_j \; P_i P_j}$$

Two basic predictions were made for this investigation. First, knowledge from experiment 2 is necessary for the experimental task of the third experiment. Based on the assumption that the hit task of experiment 3 is more difficult than the prediction task of experiment 2, the specific prediction is as follows:

$$\begin{aligned} P:\; & X_1 \rightarrow Y_1 \\ & X_2 \rightsquigarrow Y_1,\ Y_2 \\ & X_3 \rightsquigarrow Y_1,\ Y_2,\ Y_3 \end{aligned}$$

The weighting system representing this prediction is:

$$W = \begin{matrix} 0 & .5 & 1 \\ 0 & 0 & .5 \\ 0 & 0 & 0 \end{matrix}$$

Thus, classification in experiment 3 equal to or less than that on experiment 2 is seen as support of the prediction. Classification one category above that of experiment 2 is seen as a moderate error, and two categories above as a serious error. While not a particularly stringent assumption, it will serve to indicate the direction of any trends.

A second concurrent prediction was made: over trials, knowledge should increase. This prediction in effect, directly contradicts the first prediction but reflects the learning that should go on over trials. More specifically, the second prediction can be expressed as:

$$\begin{aligned} P:\quad & X_1 \curvearrowright Y_1, Y_2, Y_3 \\ & X_2 \curvearrowright Y_2, Y_3 \\ & X_3 \curvearrowright Y_3 \end{aligned}$$

The weighting system representing this prediction is:

$$W = \begin{array}{ccc} 0 & 0 & 0 \\ .5 & 0 & 0 \\ 1 & .5 & 0 \end{array}$$

As in the first prediction, classification on experiment 3 one category below that on experiment 2 is seen as a moderate error in the prediction and classification 2 categories below as a serious error.

In accordance with the first prediction, ∇P should decrease over trials (excluding the first trial which is a 'blind' trial) and in accordance with the second prediction, ∇P should increase over trials. ∇P for both predictions and for both sets of data (category and metric) are found in Tables 17 and 18. When all ages are grouped, it is evident that a knowledge of the prediction task (i.e., being classified as high knowledge on experiment 2) does assist in experiment 3. When the age groups are separated, the predictions are not as robust, although, particularly for the 11 year olds, prediction 2 i. e., over trials knowledge should increase (knowledge in experiment 3 will be greater than or equal to that on experiment 2), seems to fare somewhat better than the first prediction (knowledge on experiment 3 will be less than or equal to that on experiment 2 due to the increase~~d~~ difficulty of the third experiment's task). Tables 19 and 20 show the frequency and percentage of subjects by age in accord wih each prediction. These tables indicate that in the initial trials, the first prediction seems to fare better, particularly with the metric data. (Metric data not only reflects the direction of a move but is also sensitive to the extent of the move.) As with the analysis of knowledge categories, this particular measure considers cell frequencies and not individual subjects. In this sense, subjects who may be highly random in their actions moving in and out of all the categories will have the effect of reducing ∇P. Such random behavior (which may be

Table 19

Percentage of Subjects Over Trials in Accord with Prediction 1 (∇P_1) and Prediction 2 (∇P_2) Using Category Data

Trial	Age (in years)							
	5		7		9		11	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
1	72	83	49	78	88	55	77	66
2	83	17	61	89	83	61	77	83
3	72	78	66	83	72	55	83	55
6	78	67	77	83	77	61	66	77
10	77	72	66	72	77	77	72	89

Table 20

Percentage of Subjects Over Trials in Accord with Prediction 1 (∇P_1) and Prediction 2 (∇P_2) Using Metric Data

Trial	Age (in years)							
	5		7		9		11	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
1	62	73	89	45	56	84	67	95
2	55	77	100	56	62	79	79	96
3	68	78	100	62	56	67	45	94
6	55	77	95	67	61	73	72	89
10	55	77	84	62	79	68	78	90

interpreted as a lack of knowledge) may in fact support the prediction particularly if the subjects were categorized as low knowledge on the second experiment.

Subject by Subject Analysis

The following results are based on category data (as reflected in Table 21); however, the same trends are evident using metric data (as reflected in Table 22). The main difference between the two forms lies in the slightly more accurate performance of the eleven year olds and slightly less accurate performance of the other three age groups using metric data.

Age 5

The pattern of distribution in Table 21 reflects very clearly the clumping of subjects in the low knowledge categories. Of those classified as low or medium in experiment 2, 8 subjects who were consistently low throughout experiment 3 and 6 made adjustments to the chute bringing them closer to the target (mainly in the first orienting trial) but never recovered in that direction again. These have been classified below as stable. Three subjects may be considered highly random moving in and out of the various categories with no particular pattern. Subjects displaying this sort of behavior are those who were placed in the high knowledge category on some trials, but to suggest that they have a knowledge of the rules is perhaps misrepresenting the relationship. Low knowledge in experiment 2 may in fact be accurately predicting low (erratic) performance in experiment 3. The final subject represents what may be seen as a progressive movement towards the target, although it was not until the tenth trial that she was able to recoup her initial position. In sum then, five year olds were basically low knowledge and stable or low knowledge and erratic in their behavior.

	St	Prog	Reg	Ran
Low	10	1	0	1
Med	4	0	0	2
High	0	0	0	0

St = Stable; Prog = Progressive;
Reg = Regressive; Ran = Random

7 Year Olds

Seven year old performance as reflected in Table 21, shows much more variability; however, its pattern seems to suggest in many cases subjects have some idea of the direction to move but were having difficulty determining the size of the necessary adjustments. Only two subjects maintained the same category in experiment 3 as that in which they were placed in experiment 2; however, another four subjects have also been categorized as stable moving out of the category only once. Three subjects classified as low or medium in experiment 2, did progress to higher knowledge categories. Five others, while at times making an appropriate adjustment, could not duplicate it again and in fact moved away from the target and thus were categorized as regressive. Four subjects may be considered as operating in a random mode, moving back and forth between categories apparently not using feedback information on each trial. In sum, most seven year olds can be depicted as learning to make appropriate adjustment but as being inaccurate in those adjustments. Some however, still have difficulties with the initial orienting direction.

	St	Prog	Reg	Ran
Low	3	2	1	2
Med	2	1	4	2
High	1	0	0	0

St = Stable; Prog = Progressive;
Reg = Regressive; Ran = Random

9 Year Olds

The nine year old subject classified as low in experiment 2 (refer to Table 21), represents a serious error to the prediction (i.e., being high knowledge through out experiment 3). Three classified in the medium knowledge category in experiment 2, show progressive movement to the high knowledge category, as would be expected. Finally, two subjects were classified as random jumping in and out of all three categories. Of the 10 subjects classified as high knowledge on experiment 2, three subjects were classified as stable essentially remaining within one category over all the trials. Four of the subjects moved progressively towards the high knowledge state or moved towards such a state with over corrections or movements in the wrong direction, but always recovering and improving performance in the right direction. Only one subject made adjustments in the wrong direction without apparently recovering in the right direction and two subjects were very erratic in their movements, jumping between the knowledge categories. In sum then, nine year old performance was categorized mainly as high in experiment 2. While they apparently found the task of experiment 3 more difficult and thus were categorized as low or medium in the initial trials, they were able to orient themselves in the proper direction and progressively refine their aim.

	St	Prog	Reg	Ran
Low	1	0	0	0
Med	2	3	0	2
High	3	4	1	2

St = Stable; Prog = Progressive;
Reg = Regressive; Ran = Random

Age 11

Within this age group, no subjects were classified as low in experiment 2. Of those classified as medium (7 subjects) in experiment 2, only one remained stable in the medium category of experiment 3 (with one misadjustment). Four of the others seem to move towards the high category but with some variability within their performance.(which may evidence the still tentative nature of their knowledge-base). Two subjects were categorized as regressive, their deteriorating performance reflecting a violation of the predictions. Seven of the eleven subjects (64%) classified as high on experiment 2 remained high on experiment 3. Two others have some difficulty on the initial orienting trials but, both recover in the appropriate direction moving into the high knowledge group by the sixth trial. Finally, two subjects violate the predictions sliding from high to medium over the last few trials. In sum, 11 year old performance tended to fluctuate more around the high knowledge category (being successful fairly quickly in orienting themselves to the target area), whereas nine year olds tended to fluctuate around the medium knowledge category.

	St	Prog	Reg	Ran
Low	0	0	0	0
Med	1	4	0	2
High	7	2	2	0

St = Stable; Prog = Progressive;
Reg = Regressive; Ran = Random

Table 21

Classification of Subjects by Age Over Trials of Experiment 3 (hitting Task) Cross Tabulated with Classification in Experiment 2 (Prediction Task) Using Category Data

Experiment 2	Trial	Experiment 3 Knowledge Category											
		5 Year Olds			7 Year Olds			9 Year Olds			11 Year Olds		
	1	L L L L L L L	M M M	H H	L L	M M M M M	H			H			
	2	L L L L L L L	L M M	M L	L M	M L L M H	M			H			
Low	3	L L L L L L M	L L H	M L	L L	L L H M H	H	0	0	0	0	0	0
	6	L L L L L L L	L M H	M M	L L	L L H H M	H			H			
	10	L L L L L L L	L L M	M H	L L	L H M H H	H			H			
	1	L L L	M M M		L L L L	M M	H H H	L	M M M M	H H	L L L L	M M	H
	2	L L M	L L L		L M M H	M H	M L M	M	L M M M	H H	L M M L	M M	H
Med	3	L L H	L L H	0	L M H M	L M	M L M	M	H M H H	H H	M L M L	L L	H
	6	L L L	L L L		M M M L	L M	M M L	L	M H H H	H H	L H H H	L M	M
	10	L L H	L L L		L L M L	L L	M M L	H	L H H H	H H	M H M H	L M	M
	1				H		H	L L	M M M M M	H H H	L	M	H H H H H H H H H
	2				H		H	M M	L M M H H	M H H	H	L	H H H H H H H H H
High	3	0	0	0	H	0	H	M M	L M M M M	H M H	M	M	H M M M H H H H H
	6				H		H	L H	H M M M H	M M H	H	H	M M H H M H H H H
	10				H		H	H H	H M H H H	L H M	H	H	M M H H H H H H H

Table 22

Classification, by Age, of Subjects Over Trials of Experiment 3 (Hitting Task) Cross Tabulated with Classification in Experiment 2 (Prediction Task) Using Metric Data

Experiment 2		Experiment 3 Knowledge Category											
Trial		5 Year Olds			7 Year Olds			9 Year Olds			11 Year Olds		
Low	1	L L L L L	M M M	H H	L L L L	M M M M M M M	H H			H			
	2	L L L L M	L M M	L M	L M L H	M M L M L H H	L M			H			
	3	L L L L H	L L H	L M	L L L M	L L M H H H H	L H	0	0	0	0	0	0
	6	L L L L L	L M M	M M	L L L L	L L L H H M M	M H			H			
	10	L L L L H	L L M	H M	L L L L	L L H H M L H	M L			H			
Med	1	L L L L L	M M M		L	M M	H H	L	M M M M	H H	L L L L	M M	H
	2	L L L L L	L L L		M	M H	M M	M	L M M M	H H	L M M L	M M	H
	3	L L L L M	L L H	0	M	L H	M M	M	H M H H	H H	M L M L	L L	H
	6	L L L L L	L L L		M	L M	M L	L	M H H H	H H	L H H H	L M	M
	10	L L L L L	L L L		L	L L	M L	H	L H H H	H H	M H M H	L M	M
High	1						H	L L	M M M M M	H H H	L	M	H M H H M M M H H
	2						H	M M	L M M H H	M H H	H	L	H H M M M H H H H
	3	0	0	0	0	0	H	M M	L M M M M	H M H	M	M	H M M M H M M H M
	6						H	L H	H M M M H	M M H	H	H	M M H H M M M M H
	10							H H	H M M H H	L H M	H	H	M M M H M H M M M

Experiment 4

Experiment 3 allowed subjects to evaluate their knowledge of the task and the strategies they had developed to hit the target. The results of this evaluation will be evident in experiment 4 through changes, if any, to the declarative and procedural knowledge on which the original predictions were based.

Sample

Those subjects used in the previous three experiments were also used in experiment 4.

The Task

The task was the same as the indirect aiming task of experiments 2 and 3.

Apparatus

The same apparatus used in the previous two experiments was again used in experiment 4.

Procedure

Experiment 4 was designed to measure change, if any, in the declarative and procedural knowledge base exhibited in experiment 2 due to the procedural experiences of experiment 3. The procedures for experiment 4 exactly replicated those of experiment 2 except that only 3 targets were used. (The number of targets was reduced due to the limited attention span of the subjects, particularly the 5 year olds.) The original targets 5,3 and 4 were used and will now be referred to as targets 1,2, and 3. Thus, the research design was a 4 X 6 X 3 X 6 (Age X Order X Target X Condition) factorial with repeated measures on the last two factors.

Performance on the Prediction Task

Results from an analysis of variance will be presented first in relation to the effect of task factors on performance. The classification of subjects on the basis of knowledge categories will then be analyzed.

Task Factors .

The dependent variable for experiment 4 was subjects' error scores calculated as the distance (in inches) between the actual path of the ball and the target. As in experiment 2, both metric and category data was collected. Using category data, Table 23 shows significant main effects for age, $F\ (3,48) = 2.97$, $p < .040$, and target, $F\ (2,96) = 3.11$, $p < .048$ were obtained as well, as a significant order by target interaction $F\ (10,96) = 3.27$, $p < .001$, target by condition interaction $F\ (10,480) = 1.89$, $p < .043$ and age by order by condition interaction $F\ (75,240) = 1.37$,

Table 23

Summary Table of F-Ratios for Prediction Task Using Category Data

Part of Model	Sum of Squares	Degrees Freedom	Mean Squares	F Ratio	Probability
A^a	680.77	3	226.92	2.97	0.040**
O^b	638.34	5	127.66	1.67	0.159
AO	1336.67	15	89.11	1.16	0.327
S - within groups	3660.76	48	76.26		
T^c	155.88	2	77.94	3.11	0.049**
AT	87.07	6	25.02	0.57	0.746
OT	820.86	10	82.08	3.27	0.001*
AOT	479.01	30	15.96	0.63	0.919
TS - within groups	2402.70	96	25.02		
C^d	194.00	5	38.80	1.22	0.297
AC	480.94	15	32.06	1.01	0.442
OC	519.77	25	31.64	0.65	0.895
AOC	3267.31	75	43.56	1.37	0.037**
CS - within groups	7594.74	240	31.64		
TC	836.72	10	83.67	1.89	0.043**
ATC	479.01	30	44.11	0.91	0.600
OTC	1662.08	50	33.24	0.75	0.892
AOTC	5357.42	150	35.71	0.80	0.939
TCS - within groups	21176.32	480	44.11		

[a] Age, [b] Order, [c] Target, [d] Condition

* $p \leq .001$, ** $p \leq .05$

$\underline{p} < .037$. As noted in Table 24, using metric data a significant main effect was found with only age factor, $\underline{F}\ (3,48) = 7.10$, $\underline{p} < .001$, and a significant interaction between only the two factors target and condition, $\underline{F}\ (10,480) = 2.28$, $\underline{p} < .013$. Because the manner in which the metric data was obtained required a more refined prediction on the part of the subjects (i.e., subjects had to determine the specific path of the ball not just a broad area through which it would travel), it is not surprising greater differences are found with the metric data. Even so, the analysis of the significant effects using category data shows similar trends to those seen with the metric data. Therefore, while explicit reference will be made to trends in the metric data, the comments are also relevant to the significant effects noted with the category data.

Again, a preliminary analysis of the significant main effects and lower order interactions will preceed discussion of the higher order interactions. As in experiment 2, 7 year olds performed more poorly in the prediction task than did any of the other three age groups although in this experiment the differences in performance were not as large (particularly between the 5 and 7 year olds). No significant differences between age groups were noted using Scheffe post hoc tests with category data. Using metric data, 11 year olds performed

Table 24

Summary Table of F-Ratios for Prediction Task Using Metric Data

Part of Model	Sum of Squares	Degrees Freedom	Mean Squares	F Ratio	Probability
A[a]	36.61	3	12.20	7.10	0.00 *
O[b]	3.29	5	0.65	0.38	0.858
AO	40.27	15	2.68	1.56	0.121
S - within groups	82.44	48	1.71		
T[c]	0.93	2	0.46	1.05	0.351
AT	1.34	6	0.22	0.50	0.803
OT	4.24	10	0.42	0.96	0.482
AOT	10.14	30	0.33	0.76	0.797
TS - within groups	42.44	96	0.44		
C[d]	2.77	5	0.55	0.73	0.599
AC	15.45	15	1.03	1.36	0.166
OC	12.87	25	0.51	0.68	0.873
AOC	34.84	75	0.50	0.66	0.980
CS - within groups	37.84	240	0.75		
TC	31.51	10	1.37	2.28	0.013**
ATC	38.87	30	1.29	0.93	0.560
OTC	57.18	50	1.14	0.82	0.791
AOTC	139.53	150	0.93	0.67	0.998
TCS - within groups	661.77	480	1.37		

[a] Age, [b] Order, [c] Target, [d] Condition

* *p* < .001. ** *p* < .05

significantly better than the 5 and 7 year olds, and 9 year olds performed significantly better than the 7 year olds. Table 25 shows mean error scores for both sets of data. When these results are compared with similar results of the three targets from experiment 2 (as reflected in Table 6), using either metric or category data, all age groups decreased their error scores in experiment 4 (it should, however, be kept in mind that only 3 targets were used in experiment 4). It may be concluded that the experience of experiment 3 allowed subjects to accumulate a larger more ~~useful store of~~ declarative knowledge.

Table 26 illustrates that, as in experiment 2, 33.33% of all the balls were predetermined to hit the target. The same table shows that five year olds predicted 56.17% would hit (in contrast to 60.49% in experiment 2) and 7 year olds predicted 39.81% (in contrast to the previous 46.14%). Nine and eleven year olds were almost perfect in their prediction of hits, predicting 33.64% and 33.95%, respectively as compared with 33.02% and 35.80%, respectively in experiment 2. Thus, the younger subjects substantially improved their predictions over that of experiment 2 although they still grossly overpredicted the hit categories (predictions for experiment 2 can be found in Table 7). The older two groups were already extremely accurate in their

Table 25

Mean Error Scores by Age Using Metric and Category Data

Age (years)	Metric (in inches)	Category (in units)
5	2.242	0.503
7	3.495	0.561
9	1.727	0.225
11	1.716	0.175

Table 26

Frequency and Percentage of Predictions Made for Each Category Using Category Data

Condition	Expected		Observed							
			5		7		9		11	
	N	%	N	%	N	%	N	%	N	%
AN	54	16.67	8	2.47	21	6.4[illegible]	53	16.36	50	15.43
AF	54	16.67	6	1.58	8	2.47	30	9.26	37	11.42
H	108	33,33	182	56.17	139	39.81	109	33.64	110	33.95
BN	54	16.67	51	15.74	89	27.47	72	22.22	68	20.99
BF	54	16.67	60	18.52	67	20.68	60	18.52	59	18.21
Total	648	100	648	100	648	100	648	100	648	100

AN = Above Near, AF = Above Far, H = Hit, BN = Below Near, BF = Below Far predictions. Again, 5 and 7 year olds responded in a similar manner showing greater variability of performance than the 9 and 11 year old groups.

Increased accuracy persisted across all targets. The targets closest to the side wall (i.e., targets 1 and 2 in Figure 12) still proved the most difficult (except for the 5 year olds for whom the target closest to the base of the board was more difficult, i.e., target 2). The upper most target (target 3) proved the least difficult.

Again, the order of presentation of the conditions for each target had an effect on the error scores reflected by an order by target interaction. When presented with conditions requiring predictions above the target (i.e., AN, AF) in the initial positions followed by conditions of below the target (i.e., BN, BF), the difficult targets were most challenging. The easiest targets were also performed more poorly. Conversely, when conditions requiring predictions of below the target were presented before those requiring above target predictions, performance was enhanced on the easiest target. Performance was most poor on the easiest target under the more random sequence of conditions in which the above and below conditions were interspersed. On the other two targets performance was equally variable. This relationship is illustrated in Figure 14.

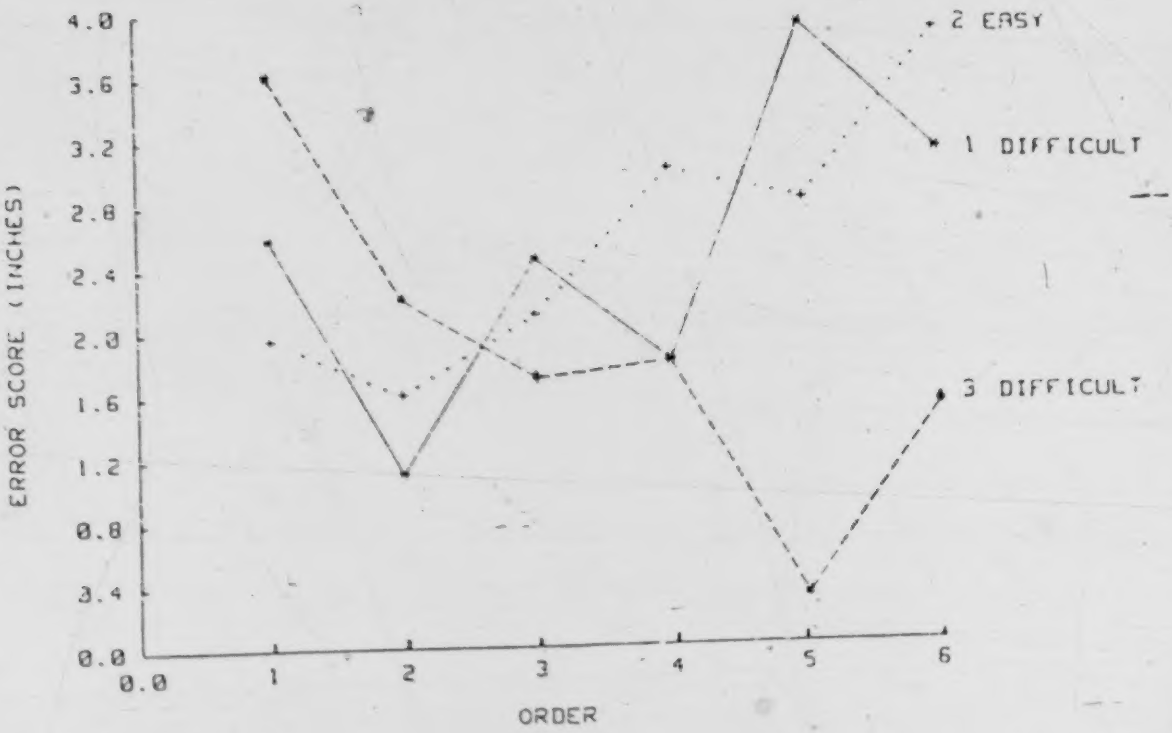

Figure 14. Mean error score on each target as a function of the order of presentation of each condition.

Similarily, the condition differentially affected performance on the various targets (reflected in the target by condition interaction). Figure 15 shows that on the upper most target (i.e., the easiest target), performance was best on the catch trials (i.e., hit) but worst on the above target predictions. Conversely, on the more difficult targets, the catch trials were performed most poorly and the above target predictions more accurately.

Finally, the age by order by condition interaction produces a rather complex pattern of effects. Five year olds performed more poorly on all conditions presented in any order except order 6, which was one of the random orders (C1,C2,AN,BF,AF,BN), on conditions below the target and near to the target (BN,BF,AN,C2). In the other age groups, basically 11 year old performance was significantly superior to both 5 year old performance (except where previously noted) and 7 year old performance, although in this latter case, one quarter of all possible combinations of order and condition for the two age groups were not significantly different. Eleven year old performance in experiment four was quite accurate thus in those cases in which 7 year olds predicted accurately, no perfomance differences were found. For example, performance of 7 year olds on all

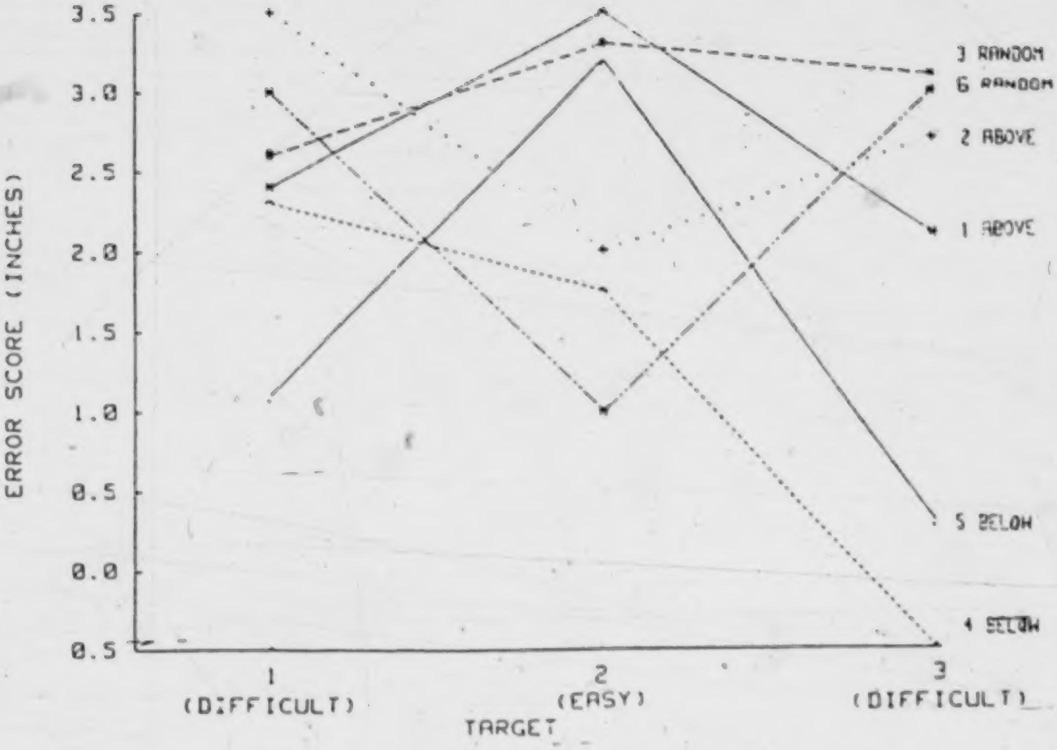

Figure 15. Mean error score on each target as a function of the condition.

targets presented in order 5 (C1,BF,C2,BN,AN,AF) and the first catch trial in all orders except order 6 (a random order) were not significantly different to 11 year old performance on each of the catch trials across orders except the first and sixth orders.

Knowledge-Performance Categories of the Subjects

As noted earlier, experiment 4 is a repeat of experiment 2 using only 3 targets. It was hypothesized that performance in experiment 4 would reflect any learning from the actual experience of making adjustments to the chute to hit the target in experiment 3. No feedback was available to subjects in experiments 2 or 4 (as the ball was never allowed to roll down the slide). In only experiment 3 were subjects provided with information about their own actions in performing the task. The size of the error in absolute terms diminished as did the distribution of subjects in each knowledge category. Table 27 the difference in distribution of subjects across knowledge categories between experiment 2 and experiment 4.(the same boundary error scores were used for establishing the categories). Clearly, a larger number of younger subjects are now classified as medium and high knowledge than they were in experiment 2. It should be noted however, that age trends are still apparent. That is, the older subjects still out-performed the younger ones. This can be seen in

Table 27

Distribution of Subjects by Age Over Knowledge Categories Using Category Boundaries from Experiment 2 for Category and Metric Data

Knowledge Category	Age (in yrs.)							
	Category				Metric			
	5	7	9	11	5	7	9	11
low	9	7	0	0	8	10	0	0
medium	7	8	6	5	9	5	8	7
high	2	3	12	13	1	3	10	11

Table 28 in which the 33.33 and 66.67 percentile points of subjects' combined error scores in experiment 4 were used to establish the category boundaries (exact scores are found in Appendix B).

Predictions made by subjects in Experiment 2 were significantly different from the actual path of the ball in all age groups. Pearson Chi squares done for the predictions in each age category were as follows: 300.19, 224.64, 46.46 and 33.98 (df=4, N=648 $p < .001$) for age groups 5, 7, 9 and 11 years respectively. Similarly, procedures done for Experiment 4 resulted in the following measures: 133.39, 94.07, 17.36* and 9.78* (df=4, N=324 $p < .001$) for ages 5, 7, 9 and 11, respectively. Only Chi squares for ages 9 and 11 were significant. From a purely descriptive point of view, these results indicate a developmental trend towards more accurate categorical predictions with age. They also indicate the role prior experience plays in subsequent performance. Increases in prediction accuracy were evident across all age groups of Experiment 4. The reduction in prediction error was about proportional across all groups; however, the reduction in error by 9 and 11 year olds brought them substantially closer to the expected frequency of category predictions.

Table 28

Distribution of Subjects by Age Over Knowledge Categories Using Category Boundaries from Experiment 4 for Category and Metric Data

Knowledge Category	Age (in yrs.)							
	Category				Metric			
	5	7	9	11	5	7	9	11
low	15	9	0	0	12	11	1	0
medium	3	8	9	6	5	4	8	8
high	0	1	9	12	1	3	9	10

CHAPTER 5

DISCUSSION

The discussion will be divided into three main sections. In the first section age trends will be discussed in terms of the strategies subjects used for each task. The second section will consider the context of each task and its influence on performance. Finally, the level of knowledge of the subjects will be discussed in light of their categorization on each task and its effect on performance in the other tasks.

Age Effects

Clear developmental trends were apparent throughout the investigation. Generally, performance improved with age as would be expected. Given the relatively lean experiential base of younger children, it is unlikely information relative to the task would be a part of their general knowledge base. This is probably even more likely with the particular sample used in this investigation. The basic principles and movement patterns underlying the task are ones which are a part of many play activities typically involved in by boys but not so commonly by girls. That is, activities such as ice hockey, street hockey, soccer, etc., all of which are based on the underlying principles used in the experimental task, are culturally normative activities for boys but not so much for girls.

Those individuals who do become involved in such activities at a young age may acquire task specific information about angular forces, rebound angles, etc. (although not necessarily formally) and be able to generalize this knowledge to other contexts much sooner than others who have not had such exposure. Liben and Goldbeck (1984) make a similar argument in explaining the differential performance of males and females on Piaget's water and plumbline tasks. They suggest that females lack experiential opportunities necessary to gain a general understanding of the basic laws of nature which underlie and constrain various physical phenomena. For example, in the context of one of Piaget's verticality tasks, when asked to draw a vertical line on the side of a hill, many females will draw a line perpendicular to the slope of the hill. Embedding information in the task instructions to encourage subjects to consider certain natural laws which invariably affect the task did little to reduce the differences in performance. Providing subjects with training in the rules and an understanding of the rules did however, substantially reduce sex related performance differences.

Liben and Goldbeck's (1984) argument is extended here beyond sex related differences, to age related differences based on differences in experiential opportunities. As no subject in this investigation had specific experience with tasks similar to the experimental task (e.g., computer games and ice hockey), any knowledge subjects had about the task, or procedures to successfully perform the task, had to come from general interactions with the environment. As mentioned earlier, given the increase of experience which is typically associated with age, developmental trends are thus expected.

Strategies Used in Making Predictions

Notwithstanding the fact that performance improved with age, 5 year olds as a group actually out-performed 7 year olds in experiment 2 (the prediction task). This reversal in trend may be accounted for, at least in part, by the nature of the assumed strategic activity of each group. A range of strategies was observed for the 5 year olds which, in general, seemed to relate to performance success. Three main strategies can be identified. Those subjects with the most extreme errors tended to predict that the ball would zig-zag around the board or roll up the right hand side of the board over the back edge in experiment two. Only the right hand wall was mentioned presumably because the chute always faced that direction. Such predictions were made no matter where the chute was placed. The second and most prevalent strategy will be called the 'hit' strategy. Subjects predicted that every trial would result in a hit on the target. They persisted in this prediction even when shown the exact position of the chute for a hit to occur. (As noted in the procedures, once subjects were shown the position of the chute for a hit and a hit demonstrated, a mark was made on the board to identify the spot for the remaining trials.) Subjects using this strategy seem to have either ignored the marker cue or assumed there were many other places along the board to which the chute could be moved which would also produce a hit. Certainly they understood what the marker indicated. When asked, they consistently said a hit.

Both these strategies (the zig zag strategy and the 'hit' strategy) may suggest the child did not yet understand that the position of the chute for the ball to hit the target is constrained to only one position and is unalterable by her own actions. Karmiloff-Smith and Inhelder (1979) made a similar observation with 4-6 year olds in their initial approaches to balancing a block on a round piece of dowelling. Subjects placed the block at any point of contact and let go assuming it would balance. The authors suggested that, as the block repeatedly fell off the dowel, the children gradually discovered that the object had properties independent of their own actions on it (p.201). Subjects' subsequent strategy was one of experimentation - a sort of fact-finding mission. Discussion of 5 year old subjects' strategies in experiment 3 (in attempting to hit the target) will show a similar pattern.

The third main strategy noted in the 5 year olds resulted in more appropriate, although not necessarily more accurate, predictions. Subjects drew a line to the side wall and then out from the side wall across the board. They then made their prediction based on their diagram. (In the first condition of experiment 2 subjects drew the line with their finger on their own volition and then made a category prediction. In the second condition, subjects were required to use a piece of chalk to draw the predicted path of the ball and the error was then measured.) While subjects consistently underestimated the rebound angle (predicting a category below the target), they did seem to accept the idea that the ball would rebound off the side wall and would do so at various angles. Subjects did not receive feedback in experiment 2 to either confirm or falsify their action, therefore, it is not surprising they persisted in their initial approach to the task.

Seven year olds showed some refinement in the strategies of the 5 year olds. All subjects in this age group understood that the ball would bounce off the side wall towards the centre of the board (based on the path they traced for the ball). They also showed some understanding of the direction the ball would take with various movements of the chute. It was the degree of knowledge in this area that separated subjects. For example, while they understood and used the mark on the board indicating the position of the chute for a hit, some felt that if the chute was even in the vicinity of the mark, a hit would still occur. Further, the chute had to be to the extreme left of the mark for subjects to suggest the ball would go above the target. Other than that, they felt it would go below the target (table 7 shows that of 216 balls positioned to go above the target in experiment 2, only 37, or 17%, were predicted correctly).

As was done by the 5 year olds, many 7 year olds used their index finger to trace out the anticipated path of the ball; however, there was a slight transition in their strategy. Nine and eleven year olds were observed to trace out the path with their eyes (sometimes confirming with the finger but very rarely). Seven year olds were beginning to evolve to this apparently more mature and abstract strategy of the 9 and 11 year olds. They fluctuated between drawing the path on the board and drawing it in the air as they 'eyed' the path. The mature strategy seems to be based on a conceptualization of where the ball would go. The immature strategy is based more on response loaded feedback from the environment (that is, the path of the ball as drawn on the board). While a move towards a more powerful and conceptually-based mature strategy, the transition strategy of the seven year olds as used on this particular task, proved to be less accurate than even that employed by the 5 year olds.

Piaget (1971) through his notion of equilibration, suggests that knowledge is least stable during a period of transition from a state of initial knowledge to a state of later, more mature knowledge. That is, the stability of some domain specific knowledge can be represented as a U-shaped function of the amount of that knowledge. Siegler (1983) makes a similar observation. He suggests that children's behavior is based on the adoption of increasingly more powerful rules or strategies. He goes on to suggest that while a new rule adopted by a child (assuming it not to be the mature rule) will be more accurate over a wider range of circumstances than the old rule, it may in fact be less accurate in certain specific circumstances in which the old rule may have been more effective. Thus, seven year olds' transition in strategy may reflect progress to a much more powerful mature strategy, one more conceptually driven than data driven. Its inefficient use at the present time, however, produces inferior results to the less powerful strategy of the 5 year olds.

Wilkinson (1984) further suggests that as the complexity of the task increases, subjects may have difficulty co-ordinating and integrating new components of the task. He suggests that stability during the development of a skill depends on both the person's level of knowledge and the complexity of the task. Based on this perspective, 7 year olds may not have acquired any new declarative knowledge (that is, they may already be able to conceptualize the task perhaps through repeated trials using the 5 year olds' strategy), but may be having some difficulty in procedualizing the more abstract strategy of mentally tracing the path of the ball.

Nine and eleven year olds were much more accurate in their predictions, although the trials designed to travel above the target proved difficult even here. With the chute positioned either near to the right hand wall and/or sharply angled towards that wall, subjects could see very clearly the general area of the side wall the ball would hit without necessarily having to invoke a conceptual rule. The angle of rebound predicted by subjects however,seemed closer to the horizontal than it did to the angle of incidence particularly the farther down the wall the chute was aimed. The proportion of observed predictions for below categories in comparison to the expected predictions for those categories confirms the over prediction in these categories for all age groups. It also indicates that 9 and 11 year olds were not basing their predictions solely on the logical rules underlying the task. If the chute was placed to the left of the hit marker, the ball would go above the target. Conversely, any time the chute lay to the right of the marker the ball had to travel below the target. Where the major 'above', 'below' and 'hit' categories were transposed, subjects were probably relying on perceptual skill more so than on the logical rules.

Strategies Used for Hitting the Target

A similar pattern of strategy refinement is evident across experiment 3 although this time the effectiveness of the strategies increased progressively with age. While the overall goal of hitting the target governed their behavior, 5 year olds generally assumed a sub-goal of exploring the behavior of the ball when the chute was moved to various positions. The chute was moved back and forth across the board (in a rather flamboyant fashion) in an attempt to find the appropriate position from which to hit the target. While subjects did seem to take note of the result of each move, they were more concerned with the absolute hit or miss result than the size of the error or the difference in error from the preceding trial. Once the ball missed the target they shifted the chute to an entirely new area of the board as though they were cataloging different positions on the board. It is possible some subjects may have had the rules reversed (some did explain them in reverse at the conclusion of the investigation). Here again, however, is evidence that subjects did not have the appropriate declarative knowledge governing this task. Karmiloff-Smith and Inhelder (1979) suggested the young subjects in their study were exploring the different ways in which they could manipulate the block. Once they had tried all the variations they could create, the authors suggest they were then in a position to choose those actions that appeared most relevant to the goal (p.201).

One five year old in this investigation, for instance, verbally planned the next move of the chute to the opposite end of the board before the ball was even released from the current position of the chute. The abrupt movement of some subjects in and out of knowledge categories (tables 21 and 22) as well as the raw data of many of those categorized throughout as low knowledge reflects the erradic and large fluctuations in their placement of the chute. The fluctuation of the error score in the age by trial interaction (table 10) is also indicative of their variability. Subjects did, however, have certain expectations as to how the ball should behave. Two subjects became quite indignant that they were not able to hit the target. After being unsuccessful on 2 and 3 targets respectively, they both suggested that there was definitely something wrong with the apparatus, they had tried all possible positions of the chute and if "things were right" they would have hit the target.

Another strategy, sometimes superimposed on the above strategy by the 5 year olds, was to select a position for the chute and then draw an imaginary line on the board with a finger to represent the path of the ball. If the path coincided with the target, the accuracy of the position was confirmed; if the two did not coincide, the chute was further adjusted. Several subjects added a novel twist to this strategy. In the event the path did not coincide with the target, these subjects reversed the procedure by drawing the line from the target to the chute. This line always coincided with the chute! Subjects may have had a preconceived notion (or theory) of what would or would not work (Karmiloff-Smith and Inhelder, 1979; De Sessa, 1981; Lawler, 1981) and thus were intent on making the evidence fit their own views or, they may have been willing to alter the position of the chute if need be. Their naivete about rebound angles combined with the necessarily arbitrary nature of drawing a line from the target to the chute may have given subjects the required flexibility to in effect, manipulate, albeit unconsciously, a successful hit each time and thus, there was no need to make any further adjustments.

Seven year olds progressed from relying solely on successes or failures for adjustments to the chute, to considering the size of their error in subsequent attempts. They still relied almost solely on drawing out the pattern before settling on a position for the chute. As noted earlier, this group recognized the results of moving the chute to the extreme regions of the board. Their initial trials may therefore have been guided by such knowledge. Subsequent refinement of the position was based on the size of the error and drawing the predicted path of the ball. It is suggested that the initial orienting trials are now being guided by some, albeit weak, conceptualization based on the extreme movements of the chute (perhaps learned, obviously outside of this experiment, by the sort of extreme experimentation done by the 5 year olds). Once a 'ball park' approximation had been made, subjects refined the position through numerous environmentally-driven adjustments. Only after this gross approximation is attained and recognized by subjects can they refine their position. In the case of the 5 year olds, this sort of orientation was not readily achieved, at least in the third experiment.

Nine and eleven year olds clearly understood directional movements of the chute but made final refinements with either a finger tracing or by standing behind the chute and 'eyeing' the path of the ball. While the 11 year olds seemed quite comfortable with their strategies and their knowledge of the task (some did mention that remembering previous positions of the chute was difficult and blamed their misses on forgetting where the chute had been positioned on previous trials), some 9 year olds, in the face of contradictory evidence (e.g., their tracing did not hit the target or, when the ball was released, it missed the target) doubted the equipment or their conceptualization of the movement behavior of the ball. In other words, while they had some confidence in their knowledge of the principles underlying changes in the path of the ball (they always came back to them), this knowledge was not quite as solid, or reliable, as the concrete evidence of drawing out the path or experiencing a miss, and was at times doubted. It should be noted that the actual physical adjustment of the chute and the drawing of the path were doubted equally (one subject noted she may have had a crooked finger on one trial!).

Vestiges of old strategies appeared across age categories particularly when subjects repeatedly met failure when they expected success. Even though the underlying logic subjects may have been using was correct, errors in the perceptual and response-loaded aspects of the response (i.e., moving the chute the appropriate distance) produced misses and diminished confidence in the procedures. On several occasions older subjects in such a situation made a large adjustment of the chute in order to re-orient themselves and make sure the ball was responding as they had predicted. They were in effect attempting to confirm their theory. Other subjects who had been 'eyeing' the path of the ball in unsuccessful attempts to hit the target, fell back to tracing out the path with their finger. Siegler (1983) suggests that children adopt specific rules or strategies based on their perceived accuracy in solving a problem. If a particular strategy seems to be failing, they may fall back on more general but less powerful strategies which they perceive to have been successful (Siegler 1981; Anderson, 1982). In this case, they may have fallen back on more general strategies which provided them with concrete information prior to releasing the ball. Using the finger to trace the path of the ball may be interpreted as a general strategy adapted for use in a specific task. Much of the literature related to counting skills, for example (Brians & Siegler 1984; Gelman, 1978;

Gelman & Gallistel, 1978) describe early strategies of using the finger to point at objects in order to tabulate them. Thus, fingering key objects or areas may be a general strategy used to highlight information the child considers critical.

The Interaction of Task-Related Factors and Performance

Interactions between various task parameters indicate very clearly that manipulating such factors as the placement of the targets, the order of their presentation and the order of presentation of the conditions to be predicted, in effect, changed the nature of the task. Lawson (1984), Brown (1978, Wellman 1983) and Flavell (1981, 1978) all emphasize the need to consider the interactive effects of not only various task variables, but person variables, knowledge variables and environmental variables in the analysis of performance effects. The degree of difficulty of a task may inhibit certain strategic activities which, under other circumstances may be a part of a child's repertoire, or may cause the subject to invoke the use of less sophisticated strategies. De Loache, Cassidy and Brown (1985) noted that the task environment affected the use of metacognitive strategies in young children. Several other investigators suggest that very young children do engage in spontaneous strategic activity on more simple tasks; however, as the task becomes increasingly complex much activity is either no longer apparent or is unsuccessful (Wellman, Ritter and Flavell, 1975; Yussen, 1974; Acredelo; Pick and Olson, 1975; DeLoache, Cassidy and Brown, 1985; Wilkinson, 1984).

It is apparent that the levels within the task factors of target position order of presentation of the targets, prediction condition and order of presentation of the conditions had a differential effect on subjects' performance.

Task Factors Affecting Subjects' Predictions

In experiments 2 and 4, predictions were made without feedback of the accuracy of performance yet interactions involving the task parameters of target, condition and order were present.

Nine and eleven year olds were more frequently guided in their prediction by prior conceptual knowledge as opposed to perceptual factors, and thus may not have been as severely affected by changes in the various task factors. However, even they made predictions by tracing out the expected path of the ball. When conditions from the same category were sequentially presented, subjects' performances improved particularly on the more difficult targets. It may be suggested that when the chute was positioned in the same vicinity on consecutive trials, subjects were able to trace out the path (either in their mind or on the board) using basically the same schema. In this instance the basic parameters of the action sequence change very little. Much less variability would be expected than in conditions in which the chute is moved to opposite ends of the board (as in the more random sequence of conditions in several of the presentation orders) such that the parameters of the action sequence vary greatly. This interaction has less to do with a knowledge of the rules than it does with the perceptually-loaded and response-loaded factors of the performance although, when a knowledge of the rules is not used, such factors can be expected to have a larger effect. On the other hand, as subjects gain greater skill in the task such task factors can be expected to produce more robust effects. As noted earlier, the movement patterns, or action sequences of the novice are at first characterized by great variability. As skill is gained, performance becomes increasingly more consistent and stable such that on repeated trials the basic pattern remains essentially the same (Glencross 1980). Thus, on trials in which there is little variability in the position of the chute, performance should become more stable. In fact, in those instances where the position of the chute changed substantially, greater variability in performance was not only expected but found.

Task Factors Affecting Subjects' Hitting Performance

The opportunity to practice accuracy on similar targets is also a factor in the performance of subjects in the hitting tasks. It becomes particularly important to the younger children in the first few trials. Thus, when targets in close vicinity to each other are presented consecutively, a particular pattern of response can be practiced (although the first target will always tend to be performed somewhat more poorly because of its novel nature). When a target in a dramatically different position is presented, the basic pattern being practiced is no longer appropriate and a whole new schema must be developed. This effect is very pronounced when either easier targets or hard targets are grouped.

Knowledge-Performance Categories

Knowledge categories for each experiment were constructed on the same basis, that is, category boundaries were established at the 33.33 and 66.67 percentiles of the error score for each experiment. In the prediction task, this resulted in a dirth of younger children (5 and 7 year olds) in the high knowledge groups and, conversely, few older children (9 and 11 year olds) in the low category. While this distribution precludes a full test of the proposition that knowledge underlying the performance of skillful prediction is necessary for the skillful performance of the hitting task (experiment

3), it does emphasize the strong influence of the developmental age of the subjects on the task throughout the investigation.

Target Hitting Knowledge (Procedural Knowledge)

Subjects very obviously were much more skillful in hitting the target directly than in having to bank the ball off the side wall to hit the target (as calculated from tables 3 and 8, 72%, 83%, 100% and 100% of the 5,7,9 and 11 year olds respectively were classified as high knowledge by the tenth trial in the direct task as compared with 11%, 33%, 72% and, 61% of 5,7,9 and 11 year olds in the indirect task). Further, the distribution of subjects across knowledge categories between the first and tenth trial shows very clearly the interaction between the complexity of the task across experiments one and three and the amount and type of learning going on. In the first few trials subjects were mainly concerned with orienting the chute to the vicinity of the target as reflected by their fluctuation back and forth between knowledge categories. Once a ball park position was attained, subjects were able to close-in on the targets through successive refinements in the position of the chute. Such adjustments should progressively move subjects towards the higher knowledge categories. This pattern is evident in experiment 1. A greater number of young children spent more time (i.e., number of trials) in the orienting phase but, even so, most were eventually able to enter the refinement phase in hitting the target. In experiment 3, a substantially greater number of subjects (particuarly younger subjects) spent a greater proportion of time in the orienting phase, some not even reaching the latter phase. As suggested earlier, this initial stage of the task is characterized by a data-driven search for the appropriate target area. Those subjects who were able to quickly zero-in on the general area were driven by prior conceptual knowledge of the appropriate direction in which to move the chute. The veracity of this knowledge was then confirmed by the path of the ball when released.

Phenomenological investigations of task learning in children suggest initial data-driven interactions with the environment provide children with information about the task (Karmiloff-Smith and Inhelder, 1979). For the youngest children, this search for information was very general. They needed to learn some of the very basic parameters controlling the task such as whether or not the ball would roll in a straight line. As suggested by Chase and Chi (1981), the novice, in this case the young child, is controlled by the physical features of the task and the expert by conceptual ideas. Comments from several nine year olds in particular suggest they used the first few trials to determine in which direction to move the chute, but, they were able to conceptualize the information and thus generalize it to other targets and positions. Through constant repetition, the children were eventually able to perceive certain consistencies in the pattern of events (Olson, 1979; De Sessa, 1981; Wall et.al., 1985). Such a process did not go on entirely within the context of this investigation. Nine and 11 year olds obviously were familiar with the fact that there would be a certain consistent pattern and needed only the first few trials to identify it. Most 5 year olds were not at the point of being able to pick it out, apparently lacking adequate experience with the task. Those children who did recognize the consistency within the pattern of events were able to develop a coherent description of the pattern and use it to predict future events. In this way, subjects developed some sort of expectation as to the path of the ball upon adjustments to the chute and used this knowledge to guide their own actions. Their actions thus became conceptually driven. Where expectations were not met, a new problem solving situation was triggered, i.e., a conflict situation was set-up (Siegler, 1983; De Sessa, 1981; Karmiloff-Smith and Inhelder, 1979) and strategies aimed at resolving the conflict, in this case determining the path of the ball in response to movements of the chute, were again invoked (Norman and Shallice, 1980; Flavell, 1978).

Very rarely, particularly within the older age group, were anticipated results in experiment 1 contradicted. That is, the pattern of expected results was well known to subjects, the appropriate interpretations were made (i.e., a correct rule structure was developed) and thus, their adjustments of the chute were correct and contradiction could not arise. In fact, directional decisions for adjustments were made instantly. Greater consideration was given to the distance over which the chute was to be moved. The rule structure underlying the task was in effect automatized and spontaneously used in response to the path of the ball on the previous trial. The rule, move the chute to the left if the ball rolled to the right of the target, move it to the left if the ball rolled to the right, became a subconscious part of the context of the task (Baars, 1983). Solutions to the task i.e., the appropriate direction of adjustment, became part of the subjects knowledge network and were automatically accessed from the context of the problem (Chase and Chi, 1981).

The older children were able to use that information as a sub-routine in the more difficult aiming task of experiment 3. Such a knowledge sequence or module may be an example of De Sessa's (1981) notion of distributed encoding. The rule and its multiple applications were better recognized by the older children who were able to transfer it to the new context of experiment 3 (De Sessa 1981; Chi, Feltovich and Glaser, 1981). They were able to use this prior knowledge to quickly orient the chute to the target and move on to the refinement phase of the task. This second phase, while still dependent on moving the chute in the appropriate direction, has a very strong perceptual component to it. Subjects must become attuned to the appropriate distance over which to move the chute. Results of the present investigation suggest 11 year olds may be more accurate in this regard over the 9 year olds (at least in experiment 3). It is evident, however, that the initial orienting phase is a pre-requisite to this refinement phase in the control of action.

Prediction Knowledge (Declarative Knowledge)

Children as young as 3 or 4 years of age bring to a task certain theories or preconceived ideas about its workings (Karmiloff-Smith and Inhelder, 1981). The fact that 5 year olds in the present investigation differentially predicted the path of the ball at different positions of the chute, and did so in a fairly consistent manner, suggests they were making their predictions based on some sort of pattern of expectations. As noted in the discussion of their strategies, their perception of the behavior of the ball and the constraints imposed on the ball by the nature of the task, often had little to do with the reality of the situation. The fact that no feedback was given in the task meant that they persisted in their ideas.

For the older subjects initial category predictions were based on a prior knowledge of the effect of moving the chute in different directions, although the precision of the prediction (i.e., its metric accuracy) may well have been a function of perceptually tracing the path of the ball. As noted earlier, the perceptual information was at times given a higher priority in the prediction than a conceptual knowledge of the underlying rule pattern and errors sometimes resulted. This created little conflict for subjects, perhaps due to the lack of feedback about the accuracy of their predictions.

Relationship Between Knowledge and Performance

Is there a relationship between performance on the prediction task of experiment 2 and skill in hitting the target in experiment 3? If such a relationship exists, is it age dependent?

Based on the assumption that knowledge from the prediction task is necessary for performance in the hitting task, the basic proposition underlying the cross tabulation procedure suggests subjects should not be categorized any higher in experiment 3 than they were in experiment 2. Two caveats must be added to this proposition. First, subjects made the initial adjustment to the chute (in experiment 3) virtually blind. The chute was always positioned to the right of the board prior to the first move and no reference points were available on which to base movement distances. Further, the angle of the chute was altered for each target in order to lessen the carry over of information between targets (except knowledge of the underlying rule structure). Performance on trial 1 may therefore be quite independent of any knowledge from experiment 3. Secondly, because subjects received feedback on their actions, it might be expected that some degree of learning would take place over trials. In this case, subjects would progress to high knowledge categories, particularly over the last few trials.

Results of the ∇P measure suggest a relationship between the two knowledge variables was present really only for 11 year olds. Based on the convergent evidence of the subject by subject analysis however, it may be suggested that the relationship is stronger than ∇P indicates. ∇P does not consider individual movement across categories. When this is considered, those individuals categorized as low in experiment 2 tended to perform in a very random fashion over trials in experiment 3 as clearly documented in Tables 21 and 22.

Five year olds were basically categorized as low and remained so through out experiment 3. Eleven year olds were mainly categorized as medium or high and did show progressive movement towards the high knowledge category in experiment 3. As noted by Wilkinson (1984) among others (e.g., Piaget, 1972; Siegler, 1983; Flavell, 1978), periods of knowledge acquisition tend to be characterized by an instability of performance. Seven and nine year olds may be considered to be in a period of knowledge transition in which they are slowly acquiring and refining more powerful strategies. As such, their performance is characterized by some instability (as compared to that of 5 and 11 year olds). This is reflected in the P measure. Providing 5 year olds with training in the prediction task may have increased their specific knowledge and provided a better test of the prediction; however, such procedures will have to wait further investigation. In the present investigation knowledge and age were closely tied.

The Effects of Performance on Knowledge

Does performance of the hitting task in which the underlying rule structure is a crucial element to successful performance, enhance the accuracy of predicting the path of the ball? That is, is procedural knowledge of the task a pre-requisite to declarative knowledge or, is declarative knowledge a pre-requisite to procedural knowledge? In many ways this is a tautological question particularly in the circumstances of this investigation. Feedback from repeated attempts at hitting the target did refine subjects' prediction knowledge; however, it is this knowledge which provides the basis on which subsequent trials are made. As noted by Glaser (1985), "knowledge fosters process, and process generates knowledge (p. 574)".

The greater subjects' success in hitting the target (with no contradictions) the greater their confidence in their knowledge. The more confidence subjects have in their knowledge (or theories) the more persistent they become in it and make predictions based on it. Wall et. al., (1985) discuss the development of this sort of confidence under the category of affective knowledge. Thus procedural knowledge allows subjects to confirm their declarative knowledge (or modify it in the event of contradictions). It also allows them to observe consistencies in events and modify subsequent procedures accordingly. Anderson (1982) suggests procedural knowledge is modified by declarative and metacognitive knowledge derived from repeated interactions with the task. Subjects' procedures were continually modified and refined from feedback of repeated trials. The older children were perhaps much more concerned with minor changes in the position of the chute than were the younger children but, each was actively involved in monitoring and analyzing the effects of each action sequence in an attempt to complete the task. In the case of the older children, it may be suggested domain-specific declarative and procedural knowledge had become embedded within the procedures. For them, declarative and procedural knowledge were tautomeric and thus inseparable. For the younger children, still very much data-driven in their approach to the task, each trial served to add to their declarative knowledge base which, in turn, was used to refine existing procedural knowledge (Anderson, 1982; Wall et al., 1985).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Development, Knowledge and, Strategies

Recent trends in the study of skill acquisition and competence have placed particular emphasis on domain-specific knowledge. Most investigations have focused on differences in performance between the expert and the novice and between age groups. As noted by Sternberg (1985), it is not surprising experts have more domain-specific knowledge in their area of expertise and further, that this richer knowledge base increases performance in the area (p.572). How does knowledge affect performance? Qualitative differences in the knowledge base between experts and novices have been observed (Chi and Koeske, 1983; Chi, Glaser and Reese, 1983; De Sessa, 1981). Such differences have also been linked to differences in strategy use (Naus and Ornstein, 1983; Lawler, 1981) and processing efficiency (Allard, 1980; Allard and Starkes, 1981).

Traditionally, level of knowledge has been associated with age differences. Typically, younger children have a much more lean knowledge network (Siegler, 1983; Brown and De Loache, 1976) which has been linked with performance differences (Karmiloff-Smith and Inhelder, 1983; Siegler, 1976). Again, differences in strategy use have been identified (Lawler, 1981; Karmiloff-Smith and Inhelder, 1983).

In sum then, three sources have predominantly been associated with performance differences: maturation, the development of strategies and, development of knowledge. Each of these factors have often been treated as independent variables but such is not the case (Wellman, 1983; Lawson, 1984). The results of the present investigation point, albeit indirectly, to the interdependence of all three factors.

The objective of this study was to investigate the relationship between declarative knowledge and procedural knowledge from a developmental perspective using a simple aiming task. Four specific questions were asked. The first three questions dealt with possible age trends related to: a) rule knowledge in the prediction task, b) the relationship between prediction knowledge (the declarative knowledge associated with knowing the rules) and hitting performance (procedural knowledge associated with instantiation of the rules) and, c) the accuracy of the predictions. In all three cases, age trends were clearly apparent both quantitatively and qualitatively. With age, subjects reduced their error scores more rapidly and displayed smaller absolute error scores. Whether such changes were linked to knowledge differences or developmental differences can not be answered in this investigation. A lack of younger subjects in the high knowledge category and older subjects in the low knowledge groups resulted in the two factors being confounded. It should be noted however, subjects were drawn randomly from three typical school populations. It may be suggested that, in general, young females do not 'have' the domain specific knowledge necessary for the task. The prevalence of the basic principles of the task as a part of common everyday tasks, meant most of the older subjects 'had' the rules without (necessarily) the benefit of formal instruction. With specific training it is possible 5 year olds could be taught the rules of the task. With such knowledge, would the 5 year olds move past the initial orientation phase of the task into the refinement stage as did the high knowledge 11 year olds?

The younger children seemed to be less affected by task variables as the task became more complex. In general, those individuals who tend to display skill in a task have a grasp of the underlying principles or knowledge structure of the task. Associated with that declarative knowledge is a store of procedural knowledge which allows the individual to flexibly recognize and apply various procedures. It may be suggested that as long as the underlying structure of the task is evident to the individual, he or she will be succesful. As conditions of the task become more complex, even though the inherent structure of the task may not change, performance will increasingly diminish. Thus, all subjects were able to skillfully perform the simple task in experiment 1. The younger subjects (typically low knowledge) were negatively affected by all conditions of the more complex aiming task of the remaining experiments. The older subjects (typically high knowledge) were affected by only the more difficult conditions of the indirect aiming task. Again, however, the same confounding argument can be applied. Is this effect related to developmental factors or knowledge factors?

Finally, the strategies used by subjects seemed to be closely tied to the level of knowledge and necessarily (at least in this study) to developmental status. For the young low knowledge subjects, strategies were based on repeated data-driven interactions with the environment. For the older high knowledge subjects, strategies were based on pre-determined action sequences based on a concptual rule structure and subsequent data-driven adjustments.

The Control of Action

Two levels of control can be identified. In the first level subjects were attempting to orient the chute to the target. In other words, they were attempting to discover the direction in which the chute had to be moved to align it to the target. In the second level, subjects rapidly acheived the general orientation and turned to focus on refining the position of the chute to hit the target.

It can be suggested that the first level of control depends heavily on the declarative knowledge of the individual. Those who understood the rules associated with movements of the chute were able to pass through this first level relatively quickly. For those who had not yet acquired the necessary knowledge, their action sequences were characterized by great variability. As the basic constraints come to be known and understood, it is suggested performances may become more consistent and stable such that the appropriate response can be made each time and the error reduced. Such refinement in the skill is indicative of the second level of control. While still using the declarative knowledge acquired in the first level of control, this level focuses on perceptual factors associated with determining the degree of adjustment needed to decrease the error. Subjects must attain the first level of control before they can effectively move to the second level. This point is echoed by Newell and Barclay, 1982) when they write, " (it) could be that there are different levels of response generalization; a broad class of generalization that, reflects the transference of the act to a range of circumstances and a narrow range of generalization that reflects the transference of details relative to the precision of the movement pattern" (p. 181). Thus, in response to the fourth question posed in this investigation - is predictive knowledge necessary for the skillful performance of a task, the answer would appear to be yes.

As noted by Glencross (1980), associated with the development of consistency is the concurrent development of the flexibility with which the skill can be performed. It is suggested that as subjects' repertoire of procedural knowledge increases they become increasingly proficient at making the appropriate adjustments to the chute in order to acheive a hit no matter the conditions under which the target is presented.

It was noted in the introduction to this investigation that intelligent behavior is distinguished by an understanding of knowledge and the flexible use of that knowledge. Likewise, skillful action is distinquished by consistency of performance and the flexibility of that performance under variable conditions. Applying the concepts developed throughout this investigation, skillful action is thus distinguished by the development of task-specific declarative knowledge and the procedural knowledge which permits its flexible use.

While this investigation focused on a descriptive analysis of the state of subjects' knowledge, just as important is the need to investigate how specific problem solving skills are acquired in the context of existing knowledge. For example, converging evidence from a number of investigators (c.f. Campione, Brown and Ferrar, 1982; Butterfield and Belmont, 1977) suggest that the central problem of the mentally retarded is not in what they know or do not know, but rather their ability to use what they know. The present investigation provides an initial glimpse of some of the potential interactions between maturation, knowledge and, strategy use in a motor task.

Recommendations

Based on the results of this investigation, the following recommendations are made:

A further conceptualization of the knowledge-base should be done. While indeed the present conceptualization provides a starting point, it proved difficult to capture in the experimental setting. Through out the investigation, it became increasingly evident that a greater differentiation of knowledge types within the major groupings was needed. For example, it may be useful to distinguish between overt and covert procedural knowledge, that is, procedureal knowledge related to the use of certain strategies and procedural knowledge related to accessing such strategies. Further, it was impossible to isolate just declarative knowledge, some procedural knowledge was always present. From this perspective, classifying subjects' declarative or procedural knowledge-base as high, medium or low can not be a pure classification and will consequently affect subsequent predictions based on such classifications. Developing a task which more clearly differentiates knowledge may help ameliorate the problem or, perhaps a more useful strategy would be to undertake a developmental investigation using a particular task and note the changes in performance over time.

The present task was a fairly useful one inasmuch as its inherent rule structure was simple and yet allowed a great deal of flexibility in changing certain aspects of the task. For example, rotational movements of the chute could have been used (as well as the lateral ones which were used) and the other side wall could have been used to effect a limited generalization. Further, the task was essentially ecologically valid. These two criteria should be kept in mind in the development of future tasks.

A follow up training study with the younger age groups is recommended in an attempt to gain equal representation in all knowledge categories from each age group. In this way, the factors of age and knowledge can be separated.

A concise and detailed record of the process of acquisition of the rules should be made. More specifically, observational data on the different and changing strategies used by subjects would appear essential in interpreting other performance data from a statistical perspective. None of the analysis techniques used provided a full and accurate picture. Infact, two of the more useful components were descriptive data of strategy use derived from simple observation and the subject by subject tabulation. Better and more appropriate technics of analysis need to be developed.

The results of this investigation, combined with those of the recommended follow up studies, will provide useful baseline data on which to base further investigations using mentally retarded youngsters.

The task should be simplified by deleting many of the task related variables. While interesting and useful in terms of annotating boundary conditions to performance, these factors and their effect on performance are peripheral to the main thrust of the investigation. More specifically, the following task factors should be limited: target position (three would be sufficient and would at the same time, decrease the number of targets and the number orders of presentationwhich were used) and condition (above, below and hit as opposed to including variations of the above and below conditions).

Computerizing the task will provide a much more efficient, convenient and reliable instrument. Care should be taken, however, to assure the similarity of the tasks, i.e., that direct manipultion of the chute to hit the target focuses on the same principles of action as manipulating a key board or joy stick in a computerized game (using a graphics tablet in connection with a computer game may be another alternative).

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APPENDIX A

PARENTAL PERMISSION/NONPERMISSION FORMS

FACULTY OF PHYSICAL EDUCATION

THE UNIVERSITY OF ALBERTA
EDMONTON 7, CANADA

Your daughter has been selected on the basis of her age, to participate in a study being done by Hilary Findlay. The task she will be asked to do involves rolling a small ball down a 15 inch metal shute and hitting a target placed at the centre of a piece of plywood. It will take approximately 45 minutes.

The project has been approved by both the Principal of Belgravia Elementary School, Mr. McBeath, and the Edmonton Public Schools research liason, Dr. Blowers.

Your permission to allow your daughter to participate is requested. Please sign this form and have your daughter return it to her teacher.

Thank you for your assistance.

- -

My daughter may participate in this project.

____
Signature of parent or guardian

____
Daughter's name

DEPARTMENT OF PHYSICAL EDUCATION
FACULTY OF PHYSICAL EDUCATION AND RECREATION

Your daughter has been selected on the basis of her age, to participate in a study being done by Hilary Findlay. The task she will be asked to do involves rolling a small ball down a 15 inch metal shute and hitting a target placed at the centre of a piece of plywood. It will take approximately 45 minutes.

If you do not wish your daughter to be involved in this project please sign this form and have her return it to her teacher.

I do not wish my daughter to be involved in this project.

(please print your name here)

signature
(parent or guardian)

APPENDIX B

BOUNDARIES FOR KNOWLEDGE CATEGORIES

Boundary Scores for the Classification of Low, Medium and, High Knowledge.

Criterial Task		Knowledge Categories		
Experiment	Task	High	Medium	Low
Exp.1	Trial 1	0.00 - 0.74	0.75 - 1.58	1.59 - 5.20
	2	0.00 - 0.36	0.37 - 1.01	1.02 - 4.81
	3	0.00 - 0.00	0.00 - 0.51	0.52 - 2.95
	6	0.00 - 0.00	0.00 - 0.00	0.00 - 3.37
	10	0.00 - 0.00	0.00 - 0.00	0.00 - 2.95
Exp.2	Category	0.00 - 0.74	0.75 - 1.32	1.33 - 2.05
	Metric	0,00 - 5.33	5.34 - 7.74	7.75 - 16.89
Exp.3	Trial 1	0.00 - 4.80	4.81 - 6.35	6.36 - 11.45
	2	0.00 - 3.85	3.89 - 6.01	6.02 - 11.85
	3	0.00 - 2.61	2.62 - 5.59	5.60 - 10.15
	6	0.00 - 0.82	0.83 - 4.01	4.02 - 13.53
	10	0.00 -0.00	0.00 - 1.99	2.00 - 13.07
Exp.4	Category	0.00 - 0.50	0.51 - 1.08	1.09 - 1.51
	Metric	0.00 - 4.13	4.14 - 6.47	6.48 - 13.89

APPENDIX C

CROSS TABULATION OF KNOWLEDGE CATEGORIES: FREQUENCY AND PERCENT OF SUBJECTS BY AGE CATEGORY BY CELL

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for Age 5 (category data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	8	2	5	1	3	4	1	4	1	3	4	1	3	3	1	4
Medium	9	4	2	3	2	5	2	3	4	2	3	6	0	5	3	1
High	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
Total	18	6	7	5	5	9	4	7	5	6	7	7	4	8	4	6

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 5 (category data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	67	39	17	11	50	17	0	50	11	6	44	22	0	50	11	6
Medium	33	17	17	0	28	6	0	22	0	11	33	0	0	28	0	6
High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100	56	34	11	78	23	0	72	11	17	77	22	0	78	11	12

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for age 7 (category data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	8	2	5	1	3	4	1	4	1	3	4	1	3	3	1	4
Medium	9	4	2	3	2	5	2	3	4	2	3	6	0	5	3	1
High	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
Total	18	6	7	5	5	9	4	7	5	6	7	7	4	8	4	6

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 7 (category data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	44	11	28	6	17	22	6	22	6	17	22	6	17	17	6	22
Medium	50	22	11	17	11	28	11	17	22	11	17	33	0	28	17	6
High	6	0	0	6	0	0	6	0	0	6	0	0	6	0	0	6
Total	100	33	39	28	28	50	6	39	28	33	39	39	22	44	22	33

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for Age 9 (category data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	2	0	1	1	1	0	1	0	0	2	0	1	1	1	0	1
Medium	3	0	3	0	0	2	1	0	2	1	0	1	2	0	0	3
High	13	3	5	5	1	6	6	1	7	5	2	5	6	1	3	9
Total	18	3	9	6	2	8	8	1	9	8	2	7	9	2	3	13

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 9 (category data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	11	0	6	6	6	0	6	0	0	22	0	6	6	6	0	6
Medium	17	0	17	0	0	22	11	0	22	6	0	6	11	0	0	17
High	72	17	28	28	6	33	33	6	39	28	11	28	33	6	17	50
Total	100	17	50	33	11	44	44	6	50	44	11	39	50	11	17	72

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for Age 11 (category data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	2	0	1	1	0	0	1	1	0	1	1	1	0	1	1	0
Medium	7	4	1	2	2	3	2	3	2	2	1	1	5	0	3	4
High	9	1	1	7	1	0	8	0	5	4	0	3	6	0	2	7
Total	18	5	3	10	3	4	11	4	7	7	2	5	11	1	6	11

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 11 (category data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	11	0	6	6	0	6	6	6	0	6	6	6	0	6	6	0
Medium	39	22	6	11	11	17	11	17	11	11	6	6	28	0	17	22
High	50	6	6	39	6	0	44	0	28	22	0	17	33	0	11	39
Total	100	28	17	56	17	22	61	22	39	39	11	28	61	6	33	61

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for age 5 (metric data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	10	5	3	2	6	4	0	7	1	2	6	4	0	6	2	2
Medium	8	5	3	0	8	0	0	6	1	1	8	0	0	8	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	10	10	6	2	14	4	0	13	2	3	14	4	0	14	2	2

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 5 (metric data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	56	28	17	0	33	22	0	39	6	11	33	22	0	33	11	11
Medium	44	28	17	0	44	0	0	36	6	6	44	0	0	44	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100	56	33	11	78	22	0	72	11	17	78	22	0	78	11	11

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for Age 7 (metric data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	12	4	6	2	5	5	2	7	2	3	6	3	3	5	2	5
Medium	5	2	1	2	0	4	1	0	3	2	1	4	0	3	2	1
High	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
Total	18	6	7	5	5	9	4	7	5	6	7	7	4	8	4	6

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 7 (metric data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	67	22	33	11	28	28	11	39	11	17	33	17	17	28	11	28
Medium	28	11	6	11	0	22	6	0	17	11	6	22	0	17	11	0
High	6	0	0	6	0	0	6	0	0	6	0	0	6	0	0	6
Total	100	33	39	28	28	50	22	39	28	33	39	39	22	44	22	33

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for Age 9 (metric data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
Medium	7	1	4	2	1	3	3	0	2	5	1	2	4	1	1	5
High	10	2	5	3	1	5	4	1	7	2	1	5	4	1	2	7
Total	18	3	9	6	2	8	8	1	9	6	2	7	9	2	3	13

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 9. (metric data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	6	0	0	6	0	0	6	0	0	6	0	0	6	0	0	6
Medium	39	6	22	11	6	17	17	0	11	28	6	11	22	6	6	28
High	56	11	28	17	6	28	22	6	39	11	6	28	22	6	11	39
Total	100	17	50	33	11	44	44	6	50	33	11	39	50	11	17	72

Cross Tabulation of Knowledge Categories of Experiment 2 with Experiment 3: Cell Frequencies for Age 11 (metric data)

Experiment 2		Experiment 3														
Category	Freq.	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Medium	6	3	2	1	2	3	1	4	1	1	2	2	2	1	3	2
High	12	2	1	9	1	1	10	0	6	6	0	3	9	0	3	9
Total	18	5	3	10	3	4	11	4	7	7	2	5	11	1	6	11

Cross Tabulation of Knowledge Categories of Experiment 2 With Experiment 3: Cell Percentages for Age 11 (metric data)

Experiment 2		Experiment 3														
Category	%	Trial 1			Trial 2			Trial 3			Trial 6			Trial 10		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Low	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Medium	33	17	11	6	11	17	6	22	6	6	11	11	11	6	17	11
High	67	11	6	50	6	6	56	0	33	33	0	17	50	0	17	50
Total	100	28	17	56	17	22	61	22	39	39	11	28	61	6	33	61